

PROCESS AREAS (OU-3)
VADOSE ZONE AND GROUNDWATER
CHARACTERIZATION WORK PLAN
REVISION 1

YERINGTON MINE SITE

August 20, 2010

PREPARED FOR:
Atlantic Richfield Company
4 CENTERPOINTE DRIVE
LA PALMA, CALIFORNIA 90623

PREPARED BY:



3264 Goni Rd, Suite 153
Carson City, Nevada 89706
(775) 883-4118

TABLE OF CONTENTS

SECTION	PAGE
SECTION 1.0 INTRODUCTION	1
1.1 Work Plan Purpose and Objectives.....	2
1.2 Site Location and Description.....	3
1.3 Phased RI Process	5
1.4 Project Management Team	6
1.5 Project Schedule.....	7
1.6 Document Organization	8
SECTION 2.0 BACKGROUND INFORMATION	9
2.1 Operational History.....	9
2.1.1 Ore Beneficiation Operations	9
2.1.2 Ancillary Support Facilities	15
2.1.3 Description of Solution and Utility Pipelines, Drains and Ditches	16
2.2 Previous Investigations	23
2.2.1 2004-2005 Process Areas Soils Investigation.....	25
2.2.2 2008 START Assessment.....	32
2.2.3 Process Areas Groundwater Investigations	34
SECTION 3.0 CONCEPTUAL SITE MODEL	37
3.1 Physical Setting.....	37
3.1.1 Geology.....	38
3.1.2 Hydrogeology	39
3.2 Contamination and Affected Media.....	42
3.2.1 Potential Sources and Release Mechanisms	42
3.3 Contaminant Migration Pathways.....	44
3.3.1 Surface Soil.....	44
3.3.2 Vadose Zone Infiltration	44
3.4 Conceptual Model Summary	49
SECTION 4.0 DATA GAPS AND DATA QUALITY OBJECTIVES	51
4.1 Data Quality Objectives.....	52
4.2 Sub-Surface Utility and Dry Well Investigations	52
4.3 Vadose Zone Characterization Locations	55
4.4 Proposed Groundwater Characterization Locations	59
SECTION 5.0 FIELD SAMPLING AND ANALYSIS PLAN.....	61
5.1 Overview of Characterization Activities	61
5.2 Vadose Zone Sampling and Analysis	63
5.2.1 Lithologic Logging and Geotechnical Characterization of Soils.....	63
5.2.2 Soil Geochemical Sampling and Analysis.....	65

TABLE OF CONTENTS - CONTINUED

SECTION	PAGE
5.3 Groundwater Sampling and Analysis	67
5.3.1 Depth-Specific Groundwater Sampling Criteria.....	68
5.3.2 Temporary Well Installation and Development.....	68
5.3.3 Depth-Specific Sample Collection Procedures.....	70
5.3.4 Well Construction, Development and Sampling	73
5.4 Vadose Zone Modeling.....	77
5.4.1 Material Properties.....	77
5.4.2 Atmospheric Input Data.....	78
5.4.3 Boundary Conditions	80
5.4.4 Initial Conditions	80
5.4.5 Interpretation of Model Results	80
5.5 Vadose Zone Monitoring	81
SECTION 6.0 QUALITY ASSURANCE PLAN.....	82
6.1 Sample Identification	83
6.2 Equipment Decontamination	84
6.3 Handling and Preservation	84
6.4 Quality Control Samples.....	88
6.5 Field Documentation.....	90
6.6 QA/QC Review	90
SECTION 7.0 DATA MANAGEMENT AND REPORTING	92
SECTION 8.0 HEALTH AND SAFETY	93
8.1 Training.....	94
8.2 Personal Protective Equipment.....	94
8.3 Ground Disturbance Safety Requirements.....	95
8.4 Work Risk Analysis	96
SECTION 9.0 REFERENCES	98

LIST OF FIGURES

Figure 1-1	Project Location
Figure 1-2	Yerington Mine Site Operable Units
Figure 1-3	Preliminary Process Areas (OU-3) RI Schedule
Figure 1-4	Schedule of Vadose Zone Work Plan Activities
Figure 2-1	Process Sub-Areas 1 through 11
Figure 2-2	Utility Pipelines and Solution Conveyance Features
Figure 2-3	Excavation Limits for the Dump Leach Surge Pond
Figure 2-4	Excavation Limits for Precipitation Plant Areas
Figure 2-5	2004-2005 Process Areas RI Groundwater Sampling Locations
Figure 2-6	Process Areas Monitoring Wells
Figure 3-1	Process Areas VLT Thickness Map
Figure 3-2	Process Areas Groundwater Flow Gradients
Figure 3-3	Process Areas Dry Well Locations
Figure 4-1	Locations of Sub-Surface Utility Features
Figure 4-2	Proposed Process Areas Vadose Zone Characterization Locations
Figure 4-3	Process Areas Proposed Monitoring Wells

LIST OF TABLES

Table 1-1	Key Project Personnel
Table 2-1	Solution Conveyance Feature Identifications
Table 2-2	Proposed Background Concentration Limits
Table 4-1	Data Quality Objectives Summary
Table 4-2	Proposed Vadose Zone Characterization Locations
Table 4-3	Proposed Monitor Well Locations
Table 5-1	Summary of FSAP Activities
Table 5-2	Sediment and Soil - Geotechnical Tests
Table 5-3	Sediment and Soil – Geochemical Analysis
Table 5-4	Zonal Sampling Field and Laboratory Parameters
Table 5-5	Analyte List for Monitor Well Sampling
Table 5-6	Annual Precipitation Values for Simulation Period
Table 5-7	Daily Average Pan Evaporation Rates
Table 6-1	Sample Containers, Preservation, and Holding Times
Table 8-1	Task Safety and Environmental Analysis Summary

LIST OF APPENDICES
(On Compact Disc)

Appendix A	2004-2005 Soils Chemical Data
Appendix B	2004-2005 Groundwater Chemical Data
Appendix C	START Report
Appendix D	Process Areas Soils Chemical Distribution Maps
Appendix E	Process Areas Soils Chemical Concentration-Depth Plots
Appendix F	Process Areas Groundwater Information
Appendix G	CH2M Hill Technical Memorandum
Appendix H	Spectrum Geophysics Sub-Surface Utilities Investigation Plan
Appendix I	Work Risk Assessment

LIST OF ACRONYMS AND ABBREVIATIONS

ABP	Acid-Base Potential	RI/FS	Remedial Investigatin and Feasibility Study
AOC	Administrative Order on Consent	RPD	Relative Percent Difference
ARAR	Applicable or Relevant and Appropriate Requirements	RPM	Remedial Project Managers
ARC	Atlantic Richfield Company	Site	Yerington Mine Site
ASTM	American Society of Testing and Materials	SIMOPS	Simultaneous Operations
BLM	Bureau of Land Management	SOP	Standard Operating Procedure
CFR	Code of Federal Regulations	SOW	Scope of Work
CSM	Conceptual Site Model	START	Superfund Technical Aessment and Response Team
DO	Dissolved Oxygen	SVOC	Semi-Volatile Organic Compound
DMP	Data Management Plan	SWCC	Soil-Water Characteristic Curve
DQO	Data Quality Objective	TDR	Time Domain Reflectometry
DSR	Data Summary Report	TDS	Total Dissolved Solids
EPA	U.S. Environmental Protection Agency	TENORM	Technologically Enhanced Naturally-Occurring Radioactive Materials
ERGS	Environmental Radiation Ground Scanner	TPH	Total Petroleum Hydrocarbons
EM	Electro-Magnetic	TOC	Total Organic Carbon
ESI	Environmental Standards Inc.	TSEA	Task Safety and Environmental Assessment
FSAP	Field Sampling and Analysis Plan	USA (North)	Utility Service Alert
GPS	Global Positioning System	USCS	Unified Soil Classification System
GPR	ground penetrating radar	VLT	Vat Leach Tails
HASP	Health and Safety Plan	VOC	Volatile Organic Compound
HFA	Hydrologic Framework Assessment	VZ	Vadose Zone
HSSE	Health Safety, Security and Environmental	WRA	Work Risk Assessment
LCS	Laboratory Control Standard	WRCC	Western Regional Climate Center
MW	Monitoring Well	YPT	Yerington Paiute Tribe
MWMP	Meteoric Water Mobility Procedure	amsl	above mean sea level
MS/MSD	Matrix Spike/Matrix Spike Duplicate	bgs	below ground surface
NAD	North American Datum	cpm	counts per minute
NDEP	Nevada Division of Environmental Protection	ft/day	feet per day
NTU	Nephelometric Turbidity Unit	ft/ft	feet per foot
ORP	Oxidation-Reduction Potential	ft/yr	feet per year
OSHA	Occupational Safety and Health Administration	g/L	grams per liter
OU	Operable Unit	gpm	gallons per minute
PA	Process Areas	mg/kg	milligrams per kilogram
PCB	Polychlorinated Biphenyl	mg/L	milligram per liter
PEL	permissible exposure levels	mL	milliliter
PPE	Personal Protective Equipment	mV	millivolt
PVC	Polyvinyl Chloride	pCi/g	picoCuries per gram
QA/QC	Quality Assurance/Quality Control	pCi/L	picoCuries per liter
QAPP	Quality Assurance Project Plan	t/kt	tons per kiloton
RAC	Removal Action Characerization	uS/cm	microSiemen per centimeter
RI	Remedial Investigation	µm	micrometer (i.e., micron)

SECTION 1.0 INTRODUCTION

Atlantic Richfield Company (ARC) prepared the *Draft Process Areas Operable Unit (OU-3) Remedial Investigation Work Plan* (RI Work Plan) dated August 30, 2007 pursuant to the Scope of Work (SOW) attached to the Administrative Order (2007 Order) for Remedial Investigation and Feasibility Study (RI/FS) for the Anaconda/Yerington Mine Site (Site). The Order was issued by the U.S. Environmental Protection Agency - Region 9 (EPA) to ARC on January 12, 2007 (EPA Docket No. 9-2007-0005). The RI Work Plan (Brown and Caldwell, 2007a) summarized data from previous soil and groundwater sampling activities conducted in 2004 and 2005 (Brown and Caldwell, 2005a and 2005b), and presented a phased scope of work for the RI.

Phased investigations in the Process Areas, a complex OU with a number of ore beneficiation and support facilities in a relatively small 280-acre area, will be based on results from previous characterization activities such as soil and groundwater data, radiometric surveys, and the removal of radiological materials (e.g., impacted soils). A phased approach promotes resource efficiency for the design of future RI activities (e.g., step-out soil sampling, mitigation of hydrocarbon-impacted soils, and monitor well installations).

Upon receipt of EPA comments dated April 13, 2009 on the Process Areas RI Work Plan, ARC submitted responses to these comments to EPA on June 9, 2009 that reiterated the benefits of a phased characterization approach to the Process Areas RI. The phase of work described herein includes an investigation of unsaturated (i.e., vadose zone) soils and groundwater, and geophysical surveys of Dry Wells and underground utilities. These investigations will be followed by additional soil sampling and other phases described in the RI Work Plan. As described in Section 1.3, phased Process Areas RI activities in 2010 and 2011 will be affected by two removal actions described in the Administrative Order on Consent and associated Scope of Work (2009 AOC/SOW)¹ dated 2009.

¹ Administrative Order on Consent and Settlement Agreement for Past Response Costs Anaconda Copper Mine, Yerington Nevada; U.S. EPA Region IX; CERCLA Docket No. 09-2009-0010.

1.1 Work Plan Purpose and Objectives

ARC's approach to characterizing Process Areas soils and groundwater was discussed in a technical meeting with EPA on August 6, 2009 and, subsequently, ARC submitted a Draft Process Areas Vadose Zone and Groundwater Characterization Work Plan on December 29, 2009. Based on EPA comments and discussions with EPA's contractor CH2M Hill, ARC has prepared this revised Process Areas Vadose Zone and Groundwater Characterization Work Plan (Vadose Zone Work Plan). This Vadose Zone Work Plan describes:

- Characterization of unsaturated soils beneath the Process Areas at 13 locations;
- Characterization of groundwater conditions and construction of three groundwater monitor wells;
- Analysis of soil geochemical and geotechnical/hydraulic properties in order to provide inputs into a vadose zone model;
- Performance of vadose zone modeling under current and anticipated climate conditions, and associated sensitivity analyses of model input parameters; and
- Compilation of field and laboratory data, and modeling results into a Data Summary Report (DSR).

The principal objective of these characterization activities is to provide the project management team listed in Section 1.4 with sufficient technical data to make informed decisions about future investigations in, and the selection of future interim and final remedies for, this OU. Planned characterization activities will focus on: 1) locations with the greatest potential for past releases of ore beneficiation solutions during Anaconda operations; and 2) the potential for meteoric water under current or future Site conditions to source chemicals to soils and the underlying alluvial aquifer. This Vadose Zone Work Plan is also consistent with the following RI study objectives, specified in Section 9.0 of the SOW (EPA, 2007):

Analyze the fate and transport of each contaminant in each medium using data sufficient to define the extent, origin, direction, and rate of movement of contaminants including: vertical and horizontal extent of contamination, contaminant concentrations, velocity and direction of contaminant movement, and a description of the contaminant and soil chemical properties and interaction.

Assess the influence of soil on type and rate of contaminant movement through the sub-surface and ultimately to the water table. Determine soil characteristics – type, holding capacity, temperature, biological activity, engineering properties. Determine soil chemistry – solubility, ion speciation, adsorption coefficients, leachability, cation exchange capacity, mineral partition coefficients, chemical and sorptive properties. Determine vadose zone characteristics – permeability, variability, porosity, moisture content, chemical characteristics, and extent of contamination.

Describe the contaminant fate and transport from the surface and sub-surface soils, including waste lines, into the unsaturated vadose zone via migration, leaching, or volatilization, and into the ambient air via fugitive dust or volatilization.

Vadose zone and groundwater characterization activities will also: 1) determine the vertical extent of chemical impacts in alluvial soils underlying areas with the greatest source potential resulting from Anaconda operations; and 2) help clarify the spatial relationships between observed soil impacts and groundwater chemical conditions beneath the Process Areas. Current water balance conditions at the Site (i.e., annual average evaporation is 9-10 times greater than annual average precipitation), as described by Huxel (1969) and Seitz et. al. (1982) and indicated by recent characterization and modeling results of the vadose zone underlying the former Anaconda Evaporation Ponds that were presented in the *Anaconda Evaporation Ponds Removal Action Characterization Data Summary Report - Revision 1* (RAC DSR; Brown and Caldwell, 2009a), suggest limited potential for meteoric water flux through the approximate 100-foot thick soil profile to groundwater beneath the Process Areas (a concept that will be tested using the information derived from the implementation of this Vadose Zone Work Plan).

1.2 Site Location and Description

The Site encompasses approximately 3,600 acres of land located about one-half mile west and northwest of the City of Yerington in Lyon County, Nevada (Figure 1-1). The Site is located in Mason Valley within the Walker River watershed. The Walker River flows northerly and northeasterly between the Site and the City of Yerington (the river is within a quarter-mile of the southern portion of the site). The Paiute Tribe Indian Reservation is located about 2.5 miles north of the Site, and the Indian Colony is located adjacent to the City of Yerington (Figure 1-1).

The physical setting of the Site is within the Basin-and-Range physiographic province, which is part of the Great Basin sagebrush-steppe ecosystem. Mason Valley occupies a structural graben (i.e., down-dropped faulted basin) typical of basin-and-range topography. The Singatse Range, located immediately south and west of the Site, is an uplifted mountain block that has been subjected to extensive hydrothermal alteration and metals mineralization in the geologic past.

Mining and ore beneficiation activities at the Site have resulted in modifications to the natural, pre-mining topography including a large open pit (occupied by a pit lake), waste rock and leached ore piles, and evaporation and tailings ponds. Many of these features comprise the OUs listed below, and those with high topographic profiles (i.e., the waste rock and spent ore piles) can exert an influence on local climate conditions (e.g., wind direction and speed).

The Site is located in a high desert environment characterized by an arid climate. Monthly average temperatures range from 33.3°F in December to 73.7°F in July. Annual average rainfall for the town of Yerington is only 5.3 inches per year, with lowest rainfall occurring between July and September (Western Regional Climate Center [WRCC], 2007). Wind speed and direction at the Site are variable as a result of natural conditions and variable topographic features created by surface mining operations. Air quality and meteorological data collected since 2002 indicate that the dominant wind directions are to the north and the northeast (Brown and Caldwell, 2009b). The Process Areas comprise one of the following eight OUs specified by EPA in the 2007 Order (Figure 1-2):

- Site-wide Groundwater (OU-1);
- Pit Lake (OU-2);
- Process Areas (OU-3);
- Evaporation Ponds and Sulfide Tailings (OU-4);
- Waste Rock Areas (OU-5);
- Oxide Tailings Areas (OU-6);
- Wabuska Drain (OU-7); and
- Arimetco Facilities (OU-8).

The main portion of the Process Areas, approximately 5,000 feet long and 2,000 feet wide (about 230 acres), includes ore beneficiation and ancillary support facilities located in the central portion of the Site. The spatial relationship of Arimetco facilities (e.g., heap leach pads currently subject to the RI/FS being performed by EPA) to the Process Areas are depicted in Figure 1-2.

1.3 Phased RI Process

The activities described in this Vadose Zone Work Plan represent a phase of work that is consistent with the draft RI Work Plan dated August 30, 2007, and the iterative approach that has been applied to Site-wide groundwater characterization activities (OU-1). The following preliminary plan for phased investigations in the Process Areas was provided in Section 6.0 of the draft RI Work Plan:

Phase 1

- Phase 1-1 Radiometric Survey
- Phase 1-2 Hydrocarbons Soils and UST Investigation
- Phase 1-3 Groundwater Investigations
- Phase 1-4 Vadose Zone Investigations
- Phase 1-5 Preliminary Building, Equipment, and Infrastructure Assessment

Phase 2

- Phase 2-1 Removal of Radioactive Materials (as required)
- Phase 2-2 Removal of Hydrocarbon-Impacted Soils and USTs (as required)
- Phase 2-3 Vadose Zone Monitoring (if required)
- Phase 2-4 Soils Investigations (Delineation Sampling)
- Phase 2-5 Additional Groundwater Investigations (second iteration, as required)

Phase 3

- Phase 3-1 Additional Soils Investigations (third iteration, as required)
- Phase 3-2 Additional Groundwater Investigations (third iteration, as required)

Phase 4

- Phase 4-1 Final Characterization of Process Components Buildings, Structures, etc.
- Phase 4-2 Demolition/Removal of Process Components, Buildings and Structures
- Phase 4-3 Characterization of Soils Beneath Removed Buildings, Structures, etc.

To date: Phase 1-1 has been completed (Team 9 START Report, 2008); Phase 1-5 has been partially completed (characterization of transite pipe within the Process Areas, subject of a removal action pursuant to the 2009 AOC/SOW); and Phase 2-1 is anticipated to be partially or fully completed in 2010-2011 with respect to the transite pipe and radiological soils removal actions pursuant to the 2009 AOC/SOW (Brown and Caldwell, 2010a and 2010b). In addition, EPA has conducted groundwater investigations of the Arimetco heap leach pads, some of which are located hydraulically up-gradient of the Process Areas. This Vadose Zone Work Plan addresses Phases 1-3 and 1-4 from the 2007 draft RI Work Plan.

As described in Section 4.0, the implementation of this Vadose Zone Work Plan will fill important data gaps associated with Process Areas soils and groundwater. The resulting data will provide the basis for subsequent characterization phases in the Process Areas. Pending further discussions with EPA, ARC anticipates that Phase 1-2 (hydrocarbon characterization), Phase 1-3 (groundwater investigations), Phase 2-2 (hydrocarbon-impacted soil removal), Phase 2-3 (vadose zone monitoring, if required) and Phase 2-4 (soil delineation sampling) can be implemented in 2011. Figure 1-3 presents a preliminary schedule for the phased Process Areas RI investigations and removal activities listed and described above. The timing of the RI activities shown on Figure 1-3 are modified from those presented in the draft RI Work Plan to reflect: 1) the two removal actions in the Process Areas to be implemented in 2010; and 2) the implementation of specific Process Areas investigations concurrently with the activities described in this Vadose Zone Work Plan, as represented by the schedule shown on Figure 1-4.

1.4 Project Management Team

The project management team consists of EPA's Remedial Project Manager (RPM; Nadia Hollan Burke) and ARC's Project Manager (Jack Oman), and their respective supporting technical staff and contractors. Document reviews are performed by members of the Yerington Technical Group, which includes representatives of EPA, the U.S. Bureau of Land Management (BLM), the Nevada Division of Environmental Protection (NDEP), the Yerington Paiute Tribe (YPT) and others. Key personnel for this Vadose Zone Work Plan are listed in Table 1-1.

Table 1-1. Key Project Personnel		
Personnel	Project Role	Company
EPA & Sub-Consultants		
Nadia Hollan Burke	RPM	EPA Region 9
	Technical Support	TetraTech
	Technical Support	CH2M Hill
Atlantic Richfield and Sub-Consultants		
Jack Oman	Project Manager	ARC
John Batchelder	Geology, Health and Safety	EnviroSolve
Jim Chatham	Geochemistry	ARC
Chuck Zimmerman	BC Project Manager	Brown and Caldwell
Guy Graening	Process Areas OU RI Manager	Brown and Caldwell
Greg Davis	Geochemistry and Hydrogeology	Brown and Caldwell
Brad Hart	Hydrogeology and Soil Hydraulics	Brown and Caldwell
Penny Bassett	Site Health and Safety Officer	Brown and Caldwell

1.5 Project Schedule

ARC plans to conduct the sub-surface utilities investigation in September 2010, and initiate the remainder of the field activities (i.e., borehole drilling and sampling and groundwater zonal sampling and monitor well construction) on or before October 5, 2010. Because the two removal actions in the Process Areas are also scheduled to begin in early October, ARC anticipates that some access logistics will need to be resolved to accommodate both the drilling activities and the removal actions. ARC plans to use the appropriate drilling and sampling equipment, and support personnel, currently on the Site installing monitor wells pursuant to the *2010 Monitor Well Work Plan - Revision 2* (Brown and Caldwell, 2010c) to perform the field activities described herein.

ARC anticipates that the scope of activities this Vadose Zone Work Plan will require approximately 12 months to complete (i.e., from the start of field activities through the submittal of the DSR). Figure 1-4 presents a schedule for these activities. Therefore, if the sub-surface investigations begin on or before October 5, 2010, ARC anticipates that the DSR will be submitted to EPA by October 1, 2011. A later start date will result in a later submittal date for the DSR.

1.6 Document Organization

Section 2.0 provides: 1) more detailed background information on the Process Areas including operational history, identification and description of ore beneficiation and ancillary support facilities, and a description of solid and liquid wastes; and 2) relevant soil and groundwater results from the 2004-2005 investigations, as well as applicable vadose zone modeling information summarized in the RAC DSR (Brown and Caldwell, 2009a).

Section 3.0 summarizes the Conceptual Site Model (CSM) elements that are relevant to the Process Areas. Section 4.0 identifies data gaps and associated data quality objectives (DQOs), and presents the rationale for the planned vadose zone characterization boreholes and monitor well locations. Section 5.0 presents the Field Sampling and Analysis Plan (FSAP) for the vadose zone and groundwater characterization activities.

Upon the completion of field activities, analytical results will be entered into the project database after appropriate quality assurance/quality control (QA/QC) procedures are performed, pursuant to the updated Quality Assurance Project Plan (QAPP - Revision 5; Environmental Standards Inc. [ESI] and Brown and Caldwell, 2009), associated standard operating procedures (SOPs) and the Site Data Management Plan (DMP; Brown and Caldwell, 2007b). These QAPP and DMP elements are described in Sections 6.0 and 7.0, respectively. Section 8.0 addresses health and safety aspects of the FSAP. Section 9.0 lists the references cited in this Vadose Zone Work Plan.

SECTION 2.0

BACKGROUND INFORMATION

This section provides background information for the Process Areas, and presents pertinent data from previous Site investigations performed in the Process Areas and the area of the former Anaconda Evaporation Ponds. These data have been used to: 1) develop the DQOs presented in Section 4.0; and 2) design the FSAP described in Section 5.0 including the identification of, and rationale for, specific locations for vadose zone characterization boreholes and groundwater monitor wells in the Process Areas.

2.1 Operational History

The following descriptions, similar to those presented in the draft RI Work Plan (Brown and Caldwell, 2007a), are based on research conducted by ARC at the Anaconda Mine archives located in Laramie, Wyoming (managed by the University of Wyoming) and the Site archives located near Yerington, Nevada (managed by the EPA).

2.1.1 Ore Beneficiation Operations

Copper in the Yerington District was initially discovered in the 1860s, with large-scale exploration of the porphyry copper system occurring in the early 1900s when the area was organized into a mining district by Empire-Nevada Copper Mining and Smelting Co. The Anaconda Company (Anaconda) became involved in the Site when it entered into a lease agreement and acquired the mining claims in 1941. The mine produced about 1.7 billion pounds of copper during its operating period (1953 to 1978).

Subsequent operators (e.g., CopperTek and Arimetco) used some of the buildings within the Process Areas for operational support, although the original processing components remained largely inactive during this period. General descriptions of Anaconda's mining and ore beneficiation activities are provided below. Figure 2-1 shows the general locations of the Process Areas features discussed in the following sections.

Mining

Anaconda mined the open pit from 1953 through 1978. Materials removed from the pit included oxide ores, sulfide ores and waste rock/alluvial overburden. Mining was conducted using electric- and diesel-powered shovels, bulldozers, scrapers, and 25-ton haul trucks (U.S. Bureau of Mines, 1958). By 1972, production reached approximately 70,000 tons per day including 28,000 tons of oxide and sulfide ore, 28,000 tons of low-grade dump leach ore, and 14,000 tons of overburden/waste rock. The mineralogical character of the copper ore mined and beneficiated by Anaconda resulted in the presence of technologically enhanced naturally-occurring radioactive materials (TENORM) at the Site.

The open pit was mined in 25-foot benches with an approximate 45 degree pit wall slope. Final dimensions of the mined pit were approximately 6,200 feet long, 2,500 feet wide and 800 feet deep. Groundwater was encountered at approximately 100 to 125 feet below ground surface, and deep wells were installed along the eastern perimeter of the pit to de-water the fractured bedrock as the depth of the pit increased. Water was pumped from each of these wells at rates up to 900 gallons per minute (gpm), and a total of up to 2,800 gpm was primarily used for mining and ore beneficiation operations and water for the Weed Heights housing community (U.S. Bureau of Mines, 1958; Skillings Mining Review, 1972).

Crushing and Grinding

Oxide and sulfide ores were crushed prior to leaching or milling, two steps for oxide ores and three steps for sulfide ores. All ores underwent coarse crushing in the Primary Crusher which was a 54-inch gyratory crusher that reduced the ore to 5 inches or less. Coarse ores exited the crusher by conveyor at a rate of approximately 1,400 tons per hour and were stored in the oxide and sulfide Coarse Ore Storage. Coarse ores were transported to the Secondary Crusher by conveyor and were further reduced in size to 7/16-inch using standard and short-head cone crushers.

Fine oxide ores exited the Secondary Crusher through an underground conveyor to the Sample Tower where a sample was collected for assay and water was sprayed onto the crushed ore to agglomerate fine material as well as control dust (U.S. Bureau of Mines, 1958 and Anaconda, 1954). Sulfide ores underwent additional crushing at the Sulfide Ore Crushing and Stockpile area located at the northwest end of the Leach Vats. Fine grinding of the sulfide ore to a grain size between 20- and 200-mesh particle size was required for flotation, and was accomplished using several rod and ball mills in sequence (Skillings Mining Review, 1972).

Leaching (Oxide Ore)

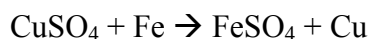
Oxide ores were loaded into the Leach Vats by conveyor and overhead loading bridge with the agglomerated ore from the Secondary Crusher, and bedded into a tank in a manner to prevent segregation and allow uninhibited circulation of leach solutions within the tank. Each tank had a capacity to hold approximately 12,000 dry tons of ore and 800,000 gallons of solution when filled to within 6 inches from the top. The vats typically operated on a 96-hour (4-day) or 120 hour (5-day) leaching cycle, with an additional 32- to 40-hour wash period, and 24 hours required to excavate and refill. The entire cycle required approximately 8 days, therefore eight leach vats were installed and used to maximize efficiency (U.S. Bureau of Mines, 1958).

A sulfuric acid leach solution was added to the oxide ores in the tanks at an initial concentration of 20 to 30 grams per liter (g/L) and circulated through the tanks for at least three hours until the acid content dropped to less than 2 g/L. The reinforced-concrete bottoms of the tanks were covered with timbers and cocoa matting as a filter to allow bottom drainage of solutions. Solutions were re-circulated and pumped at a rate of 2,000 gpm. Pregnant solutions were pumped to one of the two 286,000-gallon Solution Storage Tanks, and new solutions were transferred from the previous vat while acid was added to achieve the desired leaching strength of 40 to 60 g/L. This solution was re-circulated and then transferred to the next vat. This cycle continued for four or five leaching periods.

After leaching, the ore underwent three wash cycles which primarily used discharge water from the Peabody scrubber in the Acid Plant as well as fresh water from the supply well and leach final drain water (Anaconda, 1954). Approximately 1.4 million gallons of water were used per day for leach wash water. Spent ore, known as oxide tailings or vat leach tailings (VLT) was excavated from the Leach Vats by a clamshell digger mounted on a rolling overhead gantry crane which could position over any of the eight tanks. The digger would drop the leached ore into a hopper under which 25-ton end-dump trucks would drive, receive a load, and then haul the waste material to the VLT pile (i.e., Oxide Tailings Area or OU-6). The average time to excavate one tank was 16 hours at a rate of 40 truckloads per hour.

Cementation/Precipitation (Oxide Ore)

Copper was recovered from the leach solution by precipitating (i.e., “cementing”) the copper using scrap iron by means of the following chemical conversion:



The Precipitation Plant was divided into five separate banks or individual cells: 1) Primary, 2) Secondary, 3) Stripping/Settling, 4) Scavenger, and 5) Dump Leach. These banks of cells were operated in the following ways (Anaconda, 1954):

1. Primary Bank. 90,000 pounds of new scrap iron were loaded into each cell. Pregnant solution, with a concentration of approximately 15 to 25 g/L copper and 4-5 g/L sulfuric acid, was pumped through 4-inch lead pipes sunk into the concrete bottoms of the launder tanks and percolated upwards through the iron, overflowing to a weir box on the north east side at a rate of 700 to 900 gpm. The overflow solution discharged to the recirculation sump at the northwest end of the precipitation tanks where it was re-circulated back to the secondary bank. Re-circulation continued for four days, followed by the washing, removal and drying of the copper cement.
2. Secondary Bank. 90,000 pounds of new scrap iron was added to each cell. Solution discharged from the primary bank was re-circulated through the iron in the same manner as the primary bank. Solutions were re-circulated for five days at a pumping rate of 900 to 1,000 gpm, and then washed and excavated. Discharge solutions from the secondary bank were sent to the stripping/settling bank.

3. Stripping/Settling. This section was operated as pairs of tanks where the stripping tank contained iron and the settling tank did not. Solutions entering the stripping tank came solely from the secondary bank where additional copper was removed from the solutions prior to disposal. Solutions were re-circulated through these tanks for approximately 15 days. Final solutions from this area were sent to the Spent Solution Sump, and then ultimately returned to the Acid Plant for use as a slurry agent to wash the calcines from the acid plant to the evaporation ponds (Anaconda, 1954).
4. Scavenger. The purpose of the scavenger was to consume unused iron that was removed from the other precipitation banks after washing and separation in a trommel. Typically the residual iron was much finer and the precipitates form a dense mass. At some point, non-digestible residual material was removed from the system and discarded.
5. Dump Leach Primary and Secondary. Leach solution from the low-grade W-3 dump leach was kept entirely separate from the tank leach solutions so that the waste water could be reused. Dump leach precipitation operated similarly to the vat leach operation, and was initiated in 1965 (Mining Engineering, 1967). These solutions were re-circulated from the dump leach primary to the dump leach secondary through a separate dump leach recirculation sump.

Following cementation, the ore was washed in place and conveyed to the trommel hopper located at the southeast end of the precipitation tanks where it was further washed and the unused scrap iron separated from the copper cement. The copper cement was loaded onto hotplates (large flat drying surfaces that were heated underneath by propane gas to dry the material to approximately 12 percent moisture; Skillings Mining Review, 1972) prior to shipment. Copper cement product averaged 83 percent copper, which was hauled by trucks to the Wabuska rail spur and, eventually, to the Washoe Smelter in Anaconda, Montana for final smelting.

Concentrator (Sulfide Ore)

A froth flotation system was constructed in 1961 to beneficiate sulfide ores. Flotation and separation of sulfide ores was accomplished by: 1) mixing very finely ground ore (pulp) with water and a chemical (typically xanthate) to make the sulfide mineral hydrophobic; 2) sparging air and a surfactant chemical (typically pine oil) through the mixture to create a froth mixture; 3) allowing sulfide minerals in the pulp to float to the surface on air bubbles (froth mixture) in the aeration tank in the flotation circuit; and 4) skimming off the sulfide ores as a concentrate.

The Yerington concentrator was designed to separate solids in a 75-foot diameter thickener and re-grind the thickened solids to an even finer pulp size of minus 325 mesh (<44 microns). This re-ground material was sent through a scavenger floatation circuit, a cleaner circuit and a re-cleaner circuit. The final concentrate was thickened in a 50-foot diameter thickener, dewatered using a vacuum filter, and dried in a 24-foot rotary dryer. The finished concentrate (average 28 percent copper) was hauled by trucks to the Wabuska rail spur and shipped to Anaconda, Montana for final smelting to a pure copper product. Operation of the concentrator required approximately 3,000 gpm of water, which was obtained from groundwater production wells and recycled water from decanting the sulfide tailings and other plant operations. Sulfide tailings were deposited as a slurry mixture of solids and water (Skillings Mining Review, 1972).

Sulfuric Acid Production

Sulfuric acid was produced at Yerington in the Fluosolids and Acid Plant from raw sulfur ore shipped to the Site from the Leviathan Mine. With the depletion of Leviathan ore in 1971, sulfur ore was purchased from various other sources. The production of sulfuric acid from sulfur ore can be broken down into 5 steps: (1) crushing, (2) grinding, (3) roasting, (4) dust precipitation, and (5) contact acid plant. The final product was 93 percent sulfuric acid that was used in the tank leach and the dump leach of the oxide ore. A summary of acid production steps are provided below (Anaconda, 1954 and U.S. Bureau of Mines, 1958):

1. Crushing. Two stage crushing was completed using a jaw crusher and short-head crusher to reduce the sulfur ore to minus one inch.
2. Grinding. Rod mills were used to further reduce the ore to minus 10 mesh (<2 mm) for feed to the roaster.
3. Roasting. Fluosolid roasters were used to roast the sulfur ore, and drive SO₂ gas from the ore, which would then be converted to sulfuric acid in the subsequent steps. The ore was bedded into an 18-foot wide by 25-foot high reactor lined with insulating and fire brick. The bed of material was maintained at five feet and fluidizing air heated by propane was circulated to heat the ore to a temperature of 1,100°F to oxidize the sulfur. The burned ore or “calcines” were removed from the bottom of the reactor and disposed of in the evaporation ponds via the Calcine Ditch using spent solution pumped from cementation.

4. Dust Precipitation. Gases leaving the reactor contained 10 to 12 percent SO₂ which were cooled, and sent through the Peabody scrubber and Cottrell electrostatic precipitator to remove dust. Precipitates were collected at a rate of about 800 pounds per day and contained 30 to 40% selenium with silica. Water from the scrubber was recycled and used as wash water in the leaching vats (U.S. Bureau of Mines, 1958). Selenium precipitates were sold and shipped off-site several times per year.
5. Contact Acid Plant. The SO₂ gas entered the contact acid plant by going through a primary and secondary converter where the SO₂ was converted to SO₃. The SO₃ gas then went through a heat exchanger and the adsorption tower where it was contacted with 98 percent sulfuric acid resulting in a diluted 93 percent sulfuric acid product for use in the plant. Approximately 450 tons of 93 percent sulfuric acid were produced per day from 600 tons per day of raw sulfur ore.

2.1.2 Ancillary Support Facilities

Truck Maintenance

Vehicles and equipment were serviced on-site in the Truck Shop and other support buildings such as the Wash Rack, Grease Shops, Tire Shop, and Equipment Garage. Descriptions of vehicle maintenance activities have not been found in historical mine records so the following descriptions are based on visual observations at the Site and standard mine practices. Anaconda maintained a fleet of 30 or more 25-ton haul trucks which were used for hauling ore from the pit to the primary crusher, hauling spent ore from the leach tanks to the VLT pile, and hauling sulfur ore to the acid plant crusher. Additional road trucks were used for hauling copper cement and concentrate to the Wabuska rail spur and hauling scrap iron back from Wabuska to the plant.

Based on historical photos, it appears that the fleet was likely parked in the current location of the Equipment Garage where daily vehicle fueling and greasing would have been conducted by a mobile 'grease truck'. Historical photos also indicate that the area south of Burch Road opposite the Administration Building was used periodically for vehicle parking and equipment storage. More extensive maintenance activities such as motor repair and oil changes would have been conducted inside the Truck Shop. Tanks located inside the north end of the Truck Shop likely contained fresh motor oil and other vehicle fluids, and used motor oil was collected and stored in the Used Oil Tank.

The Wash Rack is an open concrete area with a sloping floor that collects in a drain sump on the north side and appears to drain to the Upper Truck Sludge Pond. The Wash Rack was used to hose off and steam clean a variety of vehicles and equipment, and may have included the use of degreaser soaps or solvents. Drainage from the Wash Rack is a likely source of hydrocarbons found in the Upper Truck Sludge Pond. Mine excavators, including the digging shovels, dozers, and scrapers, would likely have remained in the pit at all times and would have been serviced by the mobile grease truck in the pit, rather than traveling back to the Process Areas.

Laboratory Services

One primary, and a possible secondary, location in the Process Areas was established for laboratory analysis of mined materials for grade control and waste rock management. The south end of the Warehouse and Assay Laboratory Building was used as an assay laboratory, presumably for analysis of rock samples from the mine. Control samples such as leach solutions, precipitation solutions, and copper cement and concentrates, were also likely analyzed in this laboratory area. A 6-inch drain line exited the laboratory to a Dry Well located approximately 100 feet from the southeast corner of the building (laboratory wastes may have been directed to this Dry Well). A second laboratory area was potentially located in the northwest corner of the Change House (the nature of work conducted in this laboratory is not known).

2.1.3 Description of Solution and Utility Pipelines, Drains and Ditches

Solution and utility pipelines, drains and ditches includes all identified solution conveyance features within the Process Areas used to convey chemicals, ore beneficiation solutions and liquid wastes. Solutions transferred from point-of-origin to point-of-use to point-of-disposal by above-ground and underground piping, and surface ditches, can be categorized as follows:

- Pregnant beneficiation solutions that are metal-rich after ore leaching of the ore;
- Spent solutions that had the copper removed before reuse or disposal;
- Sulfuric acid for use in leaching, prior to application to the ore;
- Fuel (gasoline or diesel) lines distributing fuel from the storage tanks to the fuel pumps;
- Drain lines from floor drains, sumps or other sources; and
- Sewer lines connecting bathrooms and sinks to sewage disposal facilities.

Identified pipelines and conveyance features shown on Figure 2-2 are listed in Table 2-1. A number of these features were described in Sections 2.1.1 and 2.1.2, but are described below to provide a complete listing.

Table 2-1. Solution Conveyance Feature Identifications		
ID	Component	Category
UT-A	Vat Leach Pregnant Solution	Pregnant Solution
UT-B	Dump Leach Pregnant Solution	Pregnant Solution
UT-C	Sulfide Concentrate Slurry	Pregnant Solution
UT-D	Precipitation Plant Spent Solution to Pond	Spent Solution
UT-E	Precipitation Plant Spent Solution to Acid Plant	Spent Solution
UT-F	Sulfide Tails Slurry, North	Spent Solution
UT-G	Strong Sulfuric Acid to Vat Leach	Acid
UT-H	Sulfuric Acid to Dump Leach	Acid
UT-I	Acid Line	Acid
UT-J	Fuel Distribution Pipeline	Fuel
UT-K	Truck Wash Sump Drain	Drain
UT-L	Grease Pit Drain	Drain
UT-M	Fuel Tank Sump Drain	Drain
UT-N	Assay Lab Drain	Drain
UT-O	Secondary Crusher Dust Slurry Drain	Drain
UT-P	Vat Leach Pumphouse Drain	Drain
UT-Q	Sulfide Pumphouse Overflow Ditch	Drain
UT-R	Administration Sewer	Sewer
UT-S	Acid Plant Sewer	Sewer
UT-T	Leach Plant Sewer	Sewer
UT-U	Main Line Sewer	Sewer
UT-V	Weed Heights Sewer	Sewer
UT-W	Sulfide Tails Slurry, South	Spent Solution
EEE	Overflow Solution Ditch	Drain
FFF	East Solution Ditch	Drain
WW	Calcine Ditch	Spent Solution

Pregnant Solutions

Pregnant solutions were typically transported in contained pipelines generally laid on the surface or in concrete trenches in order to minimize the loss of valuable metal content. Three pregnant process solution pipelines have been identified:

Leach Vat Pregnant Solution (UT-A)

Pregnant leach solutions from the Leach Vats were transferred to the Solution Tanks and to the Precipitation Tanks by a 12-inch diameter transite pipe located in the concrete lined ditch, which is at ground level and under the roadway between the Leach Vats and the Precipitation Plant. The pipes are fully accessible for observation and repair and any spillage was collected in the Overflow Sump located southwest of the Solution Tanks.

Dump Leach Pregnant Solution (UT-B)

Low grade ore was stockpiled on a liner on the south side of Burch Drive and leached in place with sulfuric acid solution. The pregnant solution was collected on a liner underlying the ore and was transferred to the Precipitation Plant via a 12-inch diameter transite pipe laid on the ground surface. Dump Leach solution was stored in the Dump Leach Surge Pond (KK) and then transferred to the Precipitation Plant by an underground pipeline around the northwest end of the tanks where it was processed separately from the Vat Leach solutions. Most of the piping is still visible on the ground, although some sections have been removed as it nears the Dump Leach Surge Pond.

Sulfide Concentrate Slurry (UT-C)

Sulfide concentrates were piped from the flotation cells to various thickeners and settling tanks. Uncertainty exists as to the construction materials and position relative to ground surface for this conveyance, as no evidence exists of the pipes and most of the Sulfide Plant has been dismantled.

Spent Solutions

Spent solutions were transported in above-ground pipelines, underground pipelines and surface ditches and the chemistry and makeup of the spent solutions was likely to have been highly variable depending on the source of the waste. Spent solutions often contained solids slurried in the solutions. Six spent process solution pipelines have been identified:

Precipitation Plant Spent Solution to Pond (UT-D)

Spent solution consisted of iron sulfate solution and wash water generated during precipitation of the copper. The spent solution was re-circulated and stored in the Spent Solution Sump located at the northwest end of the Precipitation Plant. From there it was piped directly to the Evaporation Ponds or to the Acid Plant for slurry of the calcines. The spent solution exited the sump through underground piping, discharged into an open ditch for approximately 100 feet, and then re-entered an underground pipe that likely discharged to the north end of the Calcine Ditch.

Precipitation Plant Spent Solution to Acid Plant (UT-E)

Precipitation Plant spent solutions were also conveyed to the Acid Plant for use in the calcine slurry through enclosed piping located in the main concrete trench between the Leach Vats and Precipitation Plant. The type of piping for this conveyance is uncertain.

Sulfide Tails Slurry, North (UT-F)

Waste solutions from the Sulfide Plant exited the plant at several points in underground and above-ground 12-inch diameter transite pipes for conveyance to the Sulfide Tailings Area.

Sulfide Tails Slurry, South (UT-W)

A second Sulfide Tails Slurry line was installed which exited the Sulfide Plant and paralleled the Dump Leach Pregnant Solution pipeline for approximately 1,000 feet. The pipeline continued to the top of the Sulfide Tailings embankment where it discharged waste solutions to the tailings pond in several places. This line was constructed of 12-inch diameter transite pipe and was laid on the ground surface. Much of the original pipeline has been removed, but remnant sections are still visible as are the anchoring brackets.

Calcine Ditch (WW)

The Calcine Ditch, a major conveyance feature, was used as an unlined surface ditch to convey solid waste from the Acid Plant with the spent solutions from the Precipitation Plant to the Evaporation Ponds.

Acid Lines

Sulfuric acid was distributed to leaching components in 12-inch diameter transite pipes. Strong acid pipelines were located in concrete lined ditches at ground surface. Weak acid appears to have been conveyed in underground and above-ground pipelines. Three acid pipelines have been identified:

Strong Sulfuric Acid to Vat Leach (UT-G)

Sulfuric acid was distributed from the Acid Pant to the Vat leach Tanks in a 12-inch diameter transite pipe located in the main concrete trench. It is assumed that the 98 percent sulfuric acid was diluted to a lower concentration for conveyance in the piping but has not been confirmed.

Sulfuric Acid to Dump Leach (UT-H)

Sulfuric acid was also piped to the Dump Leach located south of Burch Drive in underground and above-ground 12-inch diameter transite pipes. The piping was primarily above-ground and was parallel to the return piping of pregnant leach solutions from the Dump Leach. It appears that the acid piping was underground for about 1,000 feet from the Precipitation Plant to the approximate location of the Tire Pile. The acid concentration in this line was likely weaker than that used in the Vat Leach Tanks, but the actual concentration has not been determined.

Acid Line (UT-I)

A small 4-inch diameter steel line is visible on the surface, but it is unclear how this line connected to the main acid distribution lines.

Fuel Lines

Fuel lines were buried underground to convey vehicle fuel, diesel and gasoline, from the storage tanks to the fuel pumps. One fuel pipeline has been identified:

Fuel Distribution Pipeline (UT-J)

Four 2-inch diameter underground steel pipelines were used to transfer various fuels from the storage tanks to the fuel pumps located on the concrete island in the middle of the driveway.

Drain Lines

Nine drain lines (i.e., underground pipelines and surface ditches that were gravity drained from minor floor drains and sumps) have been identified. These features did not originate from plant process tanks, but from ancillary support locations such as the Truck Shop or the Laboratory. Drain lines conveyed much smaller volumes than process solution pipelines.

Truck Wash Sump Drain (UT-K)

A small 2-foot by 2-foot concrete sump box is located on the north side of the concrete Wash Pad. A 6-inch diameter drain line exits the sump and drains underground approximately 50 feet to the Upper Truck Sludge Pond (BBB). Wash water from vehicle or equipment cleaning ran off through the drain line to the pond area.

Grease Pit Drain (UT-L)

A drain line, identified as the Grease Pit Drain, exited the Truck Shop to the northeast. The line appears to drain to the Lower Truck Sludge Pond, but its connection to the pond is inferred because there is no map coverage of the area to confirm this connection.

Fuel Tank Sump Drain (UT-M)

A drain line coming from the fuel tank storage area runs to the northeast. It is assumed that this line drained a collection sump similar to the Wash Pad sump, but cannot be confirmed as tanks and foundations have been removed.

Assay Lab Drain (UT-N)

A drain line exits the southeast corner of the Assay Lab and travels approximately 100 feet to the northeast into a Dry Well (no expression of the well exists at the surface).

Secondary Crusher Dust Slurry Drain (UT-O)

Water was sprayed onto the crushed ore at the Secondary Crusher for agglomeration and dust control. Runoff was collected in a sump and conveyed in an underground 8-inch diameter steel pipe to an unlined surface ditch in Area 11, which likely drained to the Sulfide Tailings Area.

Vat Leach Pumphouse Drain (UT-P)

A drain line that collected and disposed of minor spillage from vat leach solutions (pregnant and spent solutions) ran from the Vat Leach Pumphouse located at the northwest end of Vat No. 8 to a Dry Well.

Sulfide Pumphouse Overflow Ditch (UT-Q)

A third solution ditch was identified at the north end of the Process Areas, north of the Sulfide Plant, by the BLM through examination of old aerial photos. This was likely to have been an overflow ditch from the Sulfide Pumphouse. Ground surface examination by Brown and Caldwell and BLM personnel could not locate any remaining surface expression of this ditch.

Overflow Solution Ditch (FFF)

The unlined Overflow Ditch was used as a solution conveyance feature from the Overflow Sump around the northwest end of the Solution Tanks and Precipitation Plant to the Sulfide Tailings Area.

East Solution Ditch (EEE)

The East Solution Ditch was likely used to convey stormwater or other runoff solutions that collected at the Lower Truck Sludge Pond to the Calcine Ditch.

Sewer Lines

Sewer lines were constructed of 8-inch diameter steel pipes and were entirely underground. Sewer pipes collected the waste water from toilets and sinks in all ancillary support buildings. All sewer pipes were connected to one system which drained to the Sewage Solids Tank located at the north end of the Process Areas. Solids were settled in this tank and sewage water was transferred to the north end of the mine site to an unknown location. Today the sewage water from this tank is conveyed to the Weed Heights Sewage Lagoons located at the southwest corner of the Lined Evaporation Ponds. Five sewer pipelines have been identified:

Administration Sewer (UT-R)

Buildings and features serviced by this line included the Administrative Building, Change House, School House, Assay Lab, Truck Shop, Electrical Shop and Primary Crusher.

Acid Plant Sewer (UT-S)

Buildings and features serviced by this line included the Acid Plant, Vat Leach, Secondary Crusher and Carpenter's Shop.

Leach Plant Sewer (UT-T)

Buildings serviced on this line include: Solution Tanks Pumphouse and Sulfide Plant Foreman's Office.

Main Line Sewer (UT-U)

The main sewer line connects the upstream points to the Sewage Solids Tank.

Weed Heights Sewer (UT-V)

Buildings and features serviced by this line included the Weed Heights residential and community buildings and the Sulfide Plant. This line drains directly to the Sewage Solids Tank.

2.2 Previous Investigations

Previous investigations and reports that include a discussion of the Process Areas are listed below, generally in chronological order, including several documents that were summarized and referenced in the Radiological Data Compilation for the Site (Brown and Caldwell, 2005c):

- Bureau of Land Management, Carson City Field Office, 2004, BLM Yerington Mine Health and Safety Plan. Site health and safety plan prepared for BLM employees working at the Yerington Mine Site. The health and safety plan included an Appendix that summarized radiological survey results in the Process Areas and identified several areas with elevated gamma radiation. Soil samples were collected and analyzed in several areas.

- Technical Resources Group, 2005, Review of Yerington Mine Characterization Activities. Consultant report prepared for BLM Nevada State Office for the purpose of checking radiation activity levels and soil chemistry in the previously identified areas in the Process Areas and other areas of the Site. The report indicated that disequilibrium between uranium progeny may have resulted from ore beneficiation activities.
- U.S. Environmental Protection Agency, 2005, EPA Radiation and Indoor Environments National Laboratory Scanner Van Survey of the Yerington Mine Site and Surrounding Areas. A technical memorandum summarizing the data results of the scanner van radiological survey in the Process Areas and other areas on and off the mine site. Results confirmed the presence of the elevated radiological areas identified by BLM.
- Brown and Caldwell, 2005a, Data Summary Report for Process Areas Soils Investigation. Consultant report prepared for ARC summarized the analytical results of 1,129 soil samples collected in the Process Areas in 2004. Surface and sub-surface sampling was conducted around ore beneficiation components, ancillary buildings, underground pipelines, electrical transformers, and areas of hydrocarbon stained soil.
- Brown and Caldwell, 2005b, Data Summary Report for Process Areas Groundwater Conditions. Consultant report prepared for ARC described the lithologic character and groundwater quality data for the alluvial fan aquifer beneath the Process Areas, and the construction information for three monitor wells in the Process Areas.
- Rocky Mountain Environmental Consultants, 2005, Final Radiological Monitoring Report, October 2004 to April 2005, Yerington Mine Site Investigation Operations. Consultant report prepared for ARC summarizes the results of radiological health and safety monitoring in the Process Areas during field sampling activities. Includes some fugitive dust air samples collected during ground disturbance activities.
- Superfund Technical Assessment and Response Team (START), 2008, Anaconda Mine Radiation Assessment Letter Report prepared for EPA describes radiometric survey and soil sample results for the Process Areas that provide the basis for the Process Areas Radiological Materials Removal Action required by the 2009 AOC/SOW.

Two previous investigations provide the principal framework for the characterization activities described in this Vadose Zone Work Plan: 1) the 2004-2005 investigations that characterized soil and groundwater conditions (Brown and Caldwell, 2005a and 2005b, respectively); and 2) the characterization of the former Anaconda Evaporation Ponds, which included soils chemical and geotechnical characterization and vadose zone modeling (Brown and Caldwell, 2009a). All Process Areas soil analytical results from the 2004-2005 investigation are presented in Appendix A. Process Areas groundwater analytical results for the groundwater grab samples collected in 2004-2005 are provided in Appendix B. The START report is reproduced in Appendix C.

2.2.1 2004-2005 Process Areas Soils Investigation

A total of 1,129 surface and borehole soil samples were collected to a depth of 25 feet below ground surface (bgs) at 319 locations (Brown and Caldwell, 2005a). Most of the soil sample locations targeted specific ore beneficiation components such as buildings, tanks, pumps, and ditches to evaluate areas most likely to be affected by ore beneficiation activities (e.g., solution conveyances, drains, sumps or piping). In addition, grid sampling of a targeted portion of the Process Areas was also conducted. All samples were analyzed for metals, total petroleum hydrocarbons (TPH), volatile and semi-volatile organic compounds (VOCs and SVOCs), acid-base potential (ABP), pesticides, herbicides and polychlorinated biphenyls (PCBs). Samples for radiochemical analyses were collected around ore beneficiation components, piping, and other solution conveyance or storage features.

Results of this sampling effort indicated that detections of metals and radiochemicals were widespread and, except for petroleum hydrocarbons, detections of organic compounds were generally infrequent (petroleum hydrocarbons detected most frequently were TPH as diesel and motor oil). The following discussion focuses on metals and radiochemical analytical results from Process Areas soils where releases of ore beneficiation solutions or wastes from above-grade or near-surface below-grade (<5 feet bgs) facilities have been identified. The following ‘sub-areas’ within the Process Areas, shown in Figure 2-1, include the highest concentrations of metals and radiochemicals:

- Area 3 –Leach Vats,
- Area 4 – Solution Tanks,
- Area 5 – Precipitation Plant,
- Area 6 – Sulfide Plant,
- Area 7 – Calcine Ditch,
- Area 8 – Overflow Solution Ditch (former North Solution Ditch),
- Area 9 – East Solution Ditch, and
- Area 10 – North Low Area.

Maps of chemical distributions and graphs of concentrations of select chemicals versus sample depth interval are provided in Appendices D and E, respectively, for Process Areas soils in sub-areas 3 through 10 and for soils associated with underground utilities. The depth-concentration plots were developed for specific soil sampling locations, or groups of locations, that represent ‘worst-case’ conditions based on empirical observations of metal and radiochemical concentrations in Process Areas soils. These graphical presentations include background concentration limits for native alluvial soils from Sub-Area A-2, as presented in the *Background Soils Data Summary Report, Yerington Mine Site - Revision 1* (Brown and Caldwell, 2009c), reproduced below in Table 2-2.

Table 2-2. Proposed Background Concentration Limits		
Constituent	Units	Sub-Area A-2
Aluminum	(mg/kg)	25,436
Antimony	(mg/kg)	1.8
Arsenic	(mg/kg)	17
Barium	(mg/kg)	310
Beryllium	(mg/kg)	1.3
Boron	(mg/kg)	21
Cadmium	(mg/kg)	0.35
Calcium	(mg/kg)	46,625
Chromium	(mg/kg)	19
Cobalt	(mg/kg)	15
Copper	(mg/kg)	285
Iron	(mg/kg)	28,465
Lead	(mg/kg)	13
Magnesium	(mg/kg)	9,889
Manganese	(mg/kg)	729
Mercury	(mg/kg)	0.050
Molybdenum	(mg/kg)	3.3
Nickel	(mg/kg)	18
Potassium	(mg/kg)	5,229
Radium-226	(pCi/g)	2.44
Radium-228	(pCi/g)	2.13
Selenium	(mg/kg)	0.87
Silver	(mg/kg)	0.58
Sodium	(mg/kg)	2,407
Thallium	(mg/kg)	0.60
Thorium	(mg/kg)	19
Uranium	(mg/kg)	4.1
Vanadium	(mg/kg)	65
Zinc	(mg/kg)	62

Of the 25 metals and two radiochemicals evaluated, the analytes detected most frequently at concentrations greater than background limits were cadmium (23%), uranium (19%), copper (18%), radium-228 (18%), selenium (17%) and mercury (16%). Those detected in 5 to 7 percent of the samples that exceeded background limits included arsenic (6%), lead (6%), molybdenum (7%), radium-226 (7%), and thorium (7%). For the remaining metals, reported concentrations were either all less than their corresponding background limit or exceeded the background limit in less than five percent of the soil samples.

Area 3 - Leach Vats

Several of the more frequently detected metals (i.e., cadmium, copper, and molybdenum) and radium-228 were reported at concentrations exceeding background limits in multiple locations and depth intervals within Area 3 (Appendix D). Cadmium and molybdenum concentrations exceeding background limits were reported most frequently at depths ranging from 14.0 to 25.0 feet bgs at sample locations along the northeast side of the Leach Vats. At sample location PA-P15 for example, depth-concentration plots for cadmium and molybdenum illustrate a general trend of increasing concentration with depth (Appendix E). Another Area 3 location where several metals (cadmium, copper, selenium, and uranium) and radium-228 concentrations exceed background levels is the vicinity of a potential drywell at the northwest end of the Leach Vats.

As illustrated by the depth-concentration plots for sample locations PA-P19, PA-YY1 and PA-YY2 (Appendix E), cadmium concentrations exceeding background limits were reported at depths between 4.0 and 25.0 feet bgs while copper concentrations exceeding background were reported in samples at depths ranging from 4.0 to 20.0 feet bgs. Cadmium concentrations generally remained consistent with increasing depth while the copper concentrations generally declined with increasing sample depth. Isolated selenium, uranium, and radium-228 concentrations exceeding background levels were reported in samples from one or more of the three sample locations at depths ranging from 5.0 to 20.0 feet bgs. With a few scattered exceptions, ABP values were generally positive, indicating acidic conditions are not expected to be generated in soil.

Area 4 - Solution Tanks

Reported concentrations of arsenic, cadmium, copper, lead, selenium, thorium, uranium, radium-226, and radium-228 exceed background limits. Copper and selenium concentrations exceeding background were reported in deeper sample intervals at several sample locations, particularly PA-FF3 and PA-FF4 situated adjacent to the solution tanks and the southeast end of the basement foundation that may have been the associated pump house. Depth-concentration plots for these two sample locations plus PA-DD10 indicate that copper concentrations exceeding background are present from 0.5 to 20.0 feet bgs (deepest sample collected), while selenium concentrations exceeding background are reported in samples collected from 0.5 to 10.0 feet bgs (Appendix E). For the remaining analytes, concentrations exceeding background were generally confined to the shallowest soil interval.

ABP values reported for Area 4 samples were predominantly positive indicating soils were not expected to generate acidic conditions. Except for locations PA-FF3 and PA-FF4, negative ABP values (i.e., acid generating potential) were only reported for surficial soil samples, with the highest value of -19.6 tons of CaCO_3 per kiloton of material (t/kt) at sample location PA-DD10. Negative ABP values were reported to a total depth of 10.0 feet bgs at PA-FF3 and 5.0 feet bgs at PA-FF4.

Area 5 - Precipitation Plant

Reported concentrations of cadmium, copper, lead, selenium, uranium, radium-226, and radium-228 exceed background limits in samples collected at varying depths between 0.0 and 30.5 feet bgs. For most of these analytes, the highest concentrations are reported in near surface samples (i.e., up to 2.0 feet bgs), including the highest copper concentration (44,000 milligrams per kilogram [mg/kg] in sample PA-EE6) reported for a soil sample in the Process Areas. Sample PA-EE6 was collected adjacent to the sump located at the northwest end of the Precipitation Plant. Although concentrations exceeding background limits are present in samples collected at 0.0 to 2.0 feet bgs on all sides of the Precipitation Plant, concentrations exceeding background in deeper soil samples are associated with locations along the southwest side of the plant where piping, pumps, and sumps were located (i.e., PA-EE16 through PA-EE20, as shown in Appendix D).

Depth-concentration plots of copper, cadmium, selenium, uranium, radium-226, and radium-228 at location PA-EE19 (Appendix E) indicate that comparable concentrations are generally reported for samples collected at depths of 4.5 to 5.5 and 19.5 to 20.5 feet bgs, while the 24.5 to 25.5 and 29.5 to 30.5 feet bgs samples generally exhibit a trend of increasing concentration with depth. The ABP values for location PA-EE19 are consistent with these metals and radiochemical concentration trends, exhibiting positive ABP values in shallow soil samples from the 1.0 to 5.5 feet interval and negative ABP values that increased from -5 to -14 t/kt with increased depth in samples collected between 19.5 and 30.5 feet bgs.

Area 6 - Sulfide Plant

A few locations occur with cadmium, copper, radium-226, and radium-228 values that exceed background limits. Most of the Sulfide Plant soil samples were less than background limits. All ABP values were positive, indicating the soil material is not expected to generate acid.

Area 7 - Calcine Ditch

Metals (arsenic, cadmium, copper, lead, mercury, molybdenum, selenium, thallium, thorium, and uranium) and radiochemicals (radium-226 and radium-228) reported most frequently with values that exceed background limits in Process Areas soils were detected in Area 7. The maps presented in Appendix D indicate that concentrations exceeding background limits were detected along the entire length of the Calcine Ditch, at depths ranging from 3.5 to 20.0 feet bgs. Depth-concentration plots for upstream sample locations PA-WW7, PA-WW8 and PA-WW9 and downstream locations PA-WW2, PA-WW3, and PA-WW4 are illustrated in Appendix E.

At the upstream locations, no consistent trend with depth is evident. Copper and radium-226 concentrations generally decrease with increasing depth, while concentrations of radium-228 and thorium increase with depth. For other metals, concentrations either remain generally consistent with depth or vary without a clear trend. At the downstream locations, except for copper, the metals and radiochemical concentrations are highest in samples collected from 9.0 to 10.0 feet bgs and then decrease in deeper samples collected between 14.0 and 20.0 feet bgs. Positive ABP

values were reported for samples collected between 4.0 and 20 feet bgs at the two most upstream sample locations (PA-WW10 and PA-WW9). Negative ABP values were reported for all sample intervals at locations along the remainder of the Calcine Ditch.

Area 8 - Overflow Solution Ditch (former North Solution Ditch)

Arsenic, cadmium, copper, lead, mercury, molybdenum, selenium and thallium at concentrations that exceed background limits were detected in soils at varying depths and scattered sample locations along the Overflow Solution Ditch (Appendix D). Most of the metals concentrations exceeding background limits were reported in samples collected between 0.5 and 10.0 feet bgs. Radium-226 and -228, thorium, and uranium data in Area 8 soils are limited because these analytes were sampled at a single location midway along the ditch, at PA-FFF9 where concentrations were observed to be less than background limits. Except for sample locations PA-FFF11, PA-FFF15, PA-FFF16 and PA-FFF17 (downstream portion of the Overflow Solution Ditch) ABP values in soils were predominantly positive.

Area 9 - East Solution Ditch

Metals and radiochemicals reported most frequently at concentrations exceeding background limits were detected in soil samples collected at locations along the length of the East Solution Ditch (Appendix D). Concentrations exceeding background limits were detected most frequently in shallow soil samples collected between 0.5 and 5.0 feet bgs, as illustrated in the depth-concentration plots for sample locations PA-EEE13, PA-EEE14, and PA-EEE15 (Appendix E).

Cadmium, copper, lead, mercury, molybdenum, radium-228, selenium, thorium and uranium concentrations exceeded background limits in deeper sub-surface samples collected between 5.0 and 30.0 feet bgs (the most frequently reported were copper, radium-228, selenium and uranium). Negative ABP values indicating a potential for acid generation were reported for samples collected between 1.0 and 25.0 feet bgs at locations along the length of the East Solution Ditch, but the preponderance of negative ABP values are found in the northwestern third of the ditch at sample locations PA-EEE11 through PA-EEE17 (locations where a majority of metals and radiochemical concentrations that exceed background limits were reported).

Area 10 - North Low Area

Arsenic, cadmium, copper, mercury, selenium, thorium, and radium-228 were reported in multiple samples throughout the North Low Area at concentrations that exceed background limits (Appendix D). Most of the values above background limits were reported for samples collected at depths between 0.5 and 5.0 feet bgs. Only a few of the Area 10 samples were analyzed for radium-226, radium-228, thorium and uranium, including samples collected at locations PA-KK1, -KK2, and -KK3. Concentration versus depth plots for these three locations are presented in Appendix E. The radium-226 and thorium concentrations above background limits in the 9.0 to 10.0 and 14.0 to 15.0 feet bgs samples of the PA-KK3 plot are the highest concentrations detected at that location (these correspond to the sample intervals with the highest negative ABP values). ABP values reported for Area 10 sample locations are positive; negative values are reported consistently only for samples from PA-HHH8, PA-HHH16, and PA-KK3.

Underground Utilities

In addition to soil impacts associated with the specific sub-areas described above from above-grade or near-surface below-grade (<5 feet bgs) ore beneficiation facilities, soil impacts associated with various pipelines that traverse portions of the Process Areas have been identified as a result of the 2004-2005 investigations. These utilities predominantly consist of underground pipelines, but also include above-ground pipelines and ditches. The utilities conveyed pregnant and spent solutions and other liquid waste streams, fuel, acid, sewage and drainage from various Process Areas features, as illustrated in Figure 2-2. The underground pipelines that traverse Areas 3 through 10 are pregnant and spent solution, acid, sewer and drain lines.

Soil samples associated with the pipeline utilities were collected from intermediate joints, pipe bends, and locations where pipes terminated at sumps, manholes, and surface discharge points. Given the variations of pipeline configurations and depth of burial, utility-related soil samples were collected up to a depth up to 15 feet bgs. Analytes reported in multiple samples at concentrations above background limits within Areas 3 through 10 included cadmium, copper, lead, mercury, molybdenum, radium-226, radium-228, selenium, silver, thallium, thorium and uranium (copper was reported most frequently at concentrations above the background limit).

The most significant soil impact results are associated with sample PA-UT29 collected at 1.5-2.5 feet bgs from the downstream end of an open ditch in Area 8 (Overflow Solution Ditch), where spent solutions temporarily exited a pipeline, flowed about 20 to 30 feet through the open ditch, then re-entered another pipeline. This sample contained arsenic, cadmium, chromium, copper, lead, mercury, molybdenum, selenium, silver, thorium and uranium at concentrations exceeding their respective background levels. The concentrations of thorium (235 mg/kg) and uranium (150 mg/kg) in this sample were the highest reported in the Process Areas (this location also yielded elevated radiometric readings, as indicated in the START Assessment, described below). Metals at concentrations exceeding background were also reported at two additional sample locations along the same spent solutions pipeline in Area 5 (Precipitation Plant) and at 14 locations along sewer lines that traverse Areas 5, 6, 8 and 10.

2.2.2 2008 START Assessment

A radiation assessment of the Process Areas was conducted on behalf of EPA by the Region 9 (Team 9) START between July 24 and November 1, 2007 (Team 9, 2008). A copy of the START Report is provided as Appendix C. The purpose of this assessment was to characterize the extent of radiological contamination in the Process Areas. The characterization activities included establishment of an average off-site soil background concentration for radium-226, surface and sub-surface soil sampling, and gamma radiation surveys. Process Areas features that were assessed included Areas 4, 5, 6, 8, 9, 10 and 11, plus portions of Areas 1, 2, 3, 7 and 12.

Analytical results for soil samples collected during the radiation assessment were compared to an action level of 3.79 picoCuries per gram (pCi/g) radium-226 (specified in the AOC/SOW). This action level represents the sum of the average radium-226 background concentration (1.21 pCi/g) and the EPA radium-226 PRG for an outdoor worker (2.58 pCi/g). Surface soil samples were collected in Area 1 (northeast corner), Area 2 (northwest corner), Area 4, Area 5, Area 8, Area 9, Area 10, Area 11 (north corner) and Area 12. Surface soil data indicated radium-226 concentrations exceeding the site-specific action level were present in the northwest corner of Area 2, throughout Area 5, at the north end of Area 8, Area 9, and the W-3 dump leach surge pond in Area 10 (Team 9, 2008).

The highest reported concentrations, ranging from 705 to 1,080 pCi/g, were reported at sample locations in Area 5 along the southwest side of the plant where sumps, pumps, piping, and a Dry Well were located. Sub-surface samples were collected from soil borings drilled in Areas 5, 9, 10, and a location in the north corner of Area 11. Radium-226 concentrations exceeding the action level were only reported in two samples collected at a depth of 5 feet bgs from a boring drilled in the W-3 dump leach surge pond and one sample collected at a depth of 0.5-1.5 feet bgs from the boring drilled in the north corner of Area 11.

Hand-held and Environmental Radiation Ground Scanner (ERGS) gamma surveys were also conducted throughout the Process Areas. The gamma survey conducted using hand-held instruments equipped with 3-inch by 3-inch sodium iodide (NaI) detectors assessed measured gamma radiation levels relative to two- and five-times the detector background of 16,000 counts per minute (cpm). Measurements greater than twice background were considered indicative of potential contamination.

No correlation between hand-held measurements and the site-specific action level was performed, so these results were suitable only for qualitative assessment. Excluding measurements taken within some of the Area 3 leach vats, results of the hand-held gamma survey indicated measurements exceeding twice background in Area 4 (vicinity of the solution spill sump and between the three solution tanks), Area 7 (downstream end of the Calcine Ditch), Area 8 (where a northwest trending spent solution pipeline crosses the ditch, as described above for sample location PA-UT29), and Area 10 (W-3 dump leach surge pond). Measurements exceeding five-times background included Area 4 (between the solution tanks), piping alignment between Areas 4 and 5, Area 5 (vicinity of a Dry Well), and a small portion of Area 10.

The ERGS gamma survey assessed measured gamma radiation levels against a threshold of 20,828 cpm, which was considered approximately equal to the site-specific radium-226 action level of 3.79 pCi/g. Locations where ERGS gamma survey measurements exceeded the 20,828 cpm threshold included the following:

- Area 4 - the vicinity of the solution spill sump on the southwest side of the solution tanks, between the tanks, and adjacent to the northeast and southeast sides of the solution tanks;
- Area 5 – locations adjacent to the Precipitation Plant sump, the southwest side of the iron launders where pumps and piping were located, the vicinity of a Dry Well on the southwest side of the iron launders, and a location on the northeast side of the iron launders;
- Area 9 – along most of the East Solution Ditch and in particular the immediate vicinity of the juncture of the East Solution Ditch and the Overflow Solution Ditch; and
- Area 10 – the W-3 dump leach surge pond, the area between the surge pond and the East Solution Ditch, and a linear feature southeast of the surge pond that may have been a ditch.

The START Report findings have provided the basis for the removal of discrete areas of impacted soils from the Process Areas, which will be conducted in 2010 (Brown and Caldwell, 2010b). The locations of soils to be removed to an off-Site repository are shown on Figures 2-3 and 2-4. Soils shown on Figure 2-3 will be excavated to a depth of two feet bgs, and soils shown on Figure 2-4 will be excavated to a depth of three feet bgs. This removal action will include areas identified as a ‘worst-case’ location, where ore beneficiation solutions have impacted the soil profile, subject to the characterization activities described in this Vadose Zone Work Plan.

2.2.3 Process Areas Groundwater Investigations

As presented in the *Data Summary Report for Process Areas Groundwater Conditions* (Brown and Caldwell 2005b), groundwater quality beneath the Process Areas has been impacted by past ore beneficiation operations, including up-gradient and localized sources within the Process Areas (up-gradient sources may include Anaconda waste rock and leach piles and Arimetco heap leach pads). Concentrations of metals, radiochemicals, sulfate and total dissolved solids (TDS) indicative of mine-related chemicals in groundwater occur beneath the Process Areas, as well as more localized occurrences of elevated concentrations of hydrocarbons and other organic compounds (Brown and Caldwell 2005b).

Groundwater grab samples collected from the 27 boreholes at the PA-GW locations shown on Figure 2-5, and subsequent quarterly sampling of monitor wells PA-MW1 through PA-MW3 (since re-named PA-MW-1S, PA-MW-2S and PA-MW-3S; compare Figures 2-5 and 2-6), indicate three general areas of mine-related groundwater: 1) the Precipitation Plant Area (e.g., data from PA-GW-18); 2) the Northern Area including the former Sulfide Plant, the Overflow Solution Ditch, and the Dump Leach Surge Pond (e.g., data from PA-GW19); and 3) the Southern Area including the Assay Laboratory and Truck Shop (e.g., data from PA-GW6 and PA-GW9). Groundwater data from the 2004-2005 investigations are provided in Appendix B.

Monitor wells PA-MW-1S, -2S and -3S installed during the 2004-2005 investigations have been routinely monitored in accordance with the revised Groundwater Monitoring Plan (Brown and Caldwell, 2009d). Groundwater elevation and chemical concentration data for these three wells, and nearby monitor well MW-1S (Figure 2-6), are provided in Appendix F. Hydrographs (Appendix F-1) and time concentration plots (Appendix F-2) include data presented in the *First Quarter Groundwater Monitoring Report* [1Q 2010; Brown and Caldwell, 2010d]) and unpublished data collected through 2Q 2010. The following bullets summarize these data:

Groundwater Elevations

- Water levels have been measured manually in MW-1S, PA-MW-1S, PA-MW-2S, and PA-MW-3S. Data for MW-1S are available for the period November 1996 through December 2007 (MW-1S is no longer monitored; EPA, 2008). For the remaining three wells, monthly water level data are available from October 2006 through June 2010.
- The hydrographs presented in Appendix F indicate very similar responses to climate and recharge conditions. MW-1S exhibits an approximate 8.5-foot range of groundwater elevations (high of about 4,348.5 feet above mean sea level [amsl] in March 2000 and a low of about 4,340 feet amsl in October 2005). From the most recent higher head measurements in early 2007, the hydrograph indicates an approximate 6-foot decrease in water levels to the present (the lowest heads measured for the period of record).

Time-Concentration Plots

- Time-concentration plots for monitor wells MW-1S, PA-MW1-S, PA-MW-2S, and PA-MW-3S have been prepared for pH (field), total alkalinity, sulfate, chloride, dissolved arsenic, dissolved iron, and dissolved uranium. For ‘not detected’ results, the sample detection limit was plotted as the concentration value for that parameter.

- MW-1S data are generally available from March 1993 through June 2008 on a quarterly basis. Uranium data for MW-1S are not available until September 2003. Concentration data are available on a quarterly basis for the remaining three wells from 1Q 2005 through 2Q 2010.
- Field pH values indicate near-neutral conditions with minor fluctuations between 7.0 to 7.5 standard units (s.u.). Total alkalinity values for MW-1S suggest major fluctuations between 1997 and 1999, potentially resulting from inconsistent data collection methods. More recently, the values from MW-1S have been more consistent (and slightly decreasing) in the range of 300 milligrams per liter (mg/L). PA-MW-2S and PA-MW-3S indicate decreasing and increasing trends, respectively, converging to a concentration of about 400 mg/L. PA-MW-1S shows a consistent range between 170 and 200 mg/L.
- Pre-2000 sulfate and chloride data indicate largely variable and generally decreasing values, also potentially resulting from inconsistent data collection and analytical methods. Subsequently, the sulfate data indicate a more consistent range of concentrations (between about 300 and 750 mg/L) in the four wells, with decreasing values in MW-1S and PA-MW-2S. Chloride values have increased in all four wells since early 2006.
- Arsenic concentrations in MW-1S, PA-MW-1S and -3S exhibit minor fluctuations and a generally consistent range of values less than 0.02 mg/L from 2005 to the present. However, PA-MW-2S shows greater fluctuations and a general trend of slightly increasing concentrations (several values have equaled or exceeded 0.05 mg/L). Since early 2008, the arsenic concentration in PA-MW-2S has approximately doubled.
- As with pH, sulfate and alkalinity, pre-2000 iron data from MW-1S indicate variable and generally decreasing values. However, iron concentrations in the four wells have been consistent or flat since 2005, with most of the concentrations reported as ‘not detected’.
- Uranium concentration data exhibit a general trend of slightly increasing concentrations in PA-MW-1S, -2S and -3S, and a slightly decreasing trend for MW-1S. PA-MW-3S shows the highest values, with an inconsistent trend. PA-MW-1S and -2S exhibit an approximate 2x increase in uranium values from early 2005 to the present.

These data indicate: 1) generally consistent groundwater elevations throughout the Process Areas with similar responses to climate and recharge conditions; 2) increasing trends for arsenic and uranium in PA-MW-1S and -2S and over the last five years and an increase in the arsenic concentration in PA-MW-2S over the last two years; and 3) generally consistent chemical concentrations for the other parameters illustrated in Appendix F. These observations are discussed further in Section 3.0 in relation to groundwater flow velocities and travel times in the shallow alluvial aquifer beneath the Process Areas.

SECTION 3.0

CONCEPTUAL SITE MODEL

The most recent version of the CSM for the Site, Revision 3, dated January 30, 2009 (Brown and Caldwell and Integral Consulting, 2009), is currently being updated. This section focuses on the CSM elements for the Process Areas portion of the Site in the context of the: 1) former Anaconda operations described in Section 2.1; 2) observed soil and groundwater chemical concentrations and groundwater elevations described in Section 2.2; 3) a May 7, 2010 technical memorandum prepared by EPA contractor CH2M Hill entitled *Drywells, Sumps, and Source Areas Located within the Historic Anaconda Yerington Mine Site Process Areas Operable Unit* (CH2M Hill, 2010; reproduced as Appendix G of this Vadose Zone Work Plan); and 4) the groundwater elevation and chemical data presented in Appendix F. As shown on Figure 3-1, soils in the Process Areas have been covered (to varying thicknesses) with VLT materials. The CSM information presented herein provides the framework for the identification of data gaps and DQOs, and the characterization activities described in Sections 4.0 and 5.0, respectively.

3.1 Physical Setting

The Site is located on the west side of Mason Valley and the Walker River (Figure 1-1). Mason Valley is a structural basin surrounded by uplifted mountain ranges within the Basin and Range physiographic province of west-central Nevada. Mason Valley is bordered by the Singatse Range to the west, the Desert Mountains to the north, and the Wassuk Range to the east. Specifically, the Site is located on the eastern flank of the Singatse Range along the distal edge of an alluvial fan between the Singatse Range and the flood plain of the Walker River. The head of the alluvial fan on which the Site is located is at an elevation of approximately 4,800 feet amsl and the base is between 4,380 feet and 4,420 feet amsl. At the lower elevations, the fan deposits merge with the fluvial deposits of the Walker River flood plain. The main portion of the Process Areas is located at an elevation of 4,400 to 4,500 feet.

3.1.1 Geology

The Singatse Range is primarily composed of granitic and volcanic rocks, with minor outcrops of metamorphic rocks. The Singatse Range has been subject to metals mineralization, as evidenced by the large copper porphyry ore deposit at the Yerington Mine and other nearby mines. Proffett and Dilles (1984) published a geologic map of the Yerington Mining District that describes these features. Seitz et. al. (1982) described the geologic setting of the area around the Site based on existing information and sub-surface information obtained through the drilling of test wells north of the site by the U.S. Geological Survey in 1978. Alluvial fan deposits along the west margin of the valley underlie the Process Areas and stream- and lake-deposited materials on the valley floor underlie the tailings and evaporation ponds (Seitz et. al.; 1982).

Unconsolidated alluvial deposits derived by erosion of the uplifted mountain block of the Singatse Range and alluvial materials deposited by the Walker River fill the structural basin occupied by Mason Valley in the vicinity of the mine site. These unconsolidated deposits comprise four geologic units: younger alluvium (including lacustrine deposits associated with Lake Lahontan), younger fan deposits, older alluvium and older fan deposits (Huxel, 1969).

As part of the Yerington Mining District, the Site is located within a large area characterized by surface expressions of base and precious metals mineralization and associated hydrothermal alteration, of bedrock outcrops of granitic and volcanic rocks (Proffett and Dilles, 1984). The Yerington ore deposit is a disseminated porphyry copper deposit. Copper mineralization is associated with an intrusion of quartz-monzonite porphyry into a granodiorite mass (U.S. Bureau of Mines, 1958). The primary ore minerals are chrysocolla, a copper-alumina silicate, and chalcopyrite, a copper sulfide mineral. Other metals commonly associated with porphyry copper deposits (e.g., arsenic, molybdenum, uranium, zinc) often occur in a larger alteration halo around the ore body, which is the case at the Site. The mineralogical characteristics of the ore and waste rock mined from the open pit resulted in the occurrence of TENORM at the Site.

The occurrence of a potentially extensive alteration halo in the local country rock around the Yerington copper ore body, in conjunction with the alteration haloes associated with the nearby Blue Stone, Bear and MacArthur copper deposits, is likely to result in elevated metals concentrations in the distal alluvial fan deposits underlying the Process Areas. This condition of elevated metals concentrations in soils is consistent with the results of Shacklette and Boerngen (1984) for the Yerington area. More Site-specific chemical data for background soils, located immediately west of the Site, are presented in the *Background Soils Data Summary Report - Revision 1* (Brown and Caldwell, 2009c).

3.1.2 Hydrogeology

The principal source of water in the Yerington area of Mason Valley is from the Walker River (Huxel, 1969). The East and West Forks of the Walker Rivers originate in the Sierra Nevada and merge south of the Site. The Walker River then flows northward through Mason Valley to Walker Gap. From Walker Gap, the river turns eastward and then flows southeastward to Weber Reservoir, and ultimately to its terminus at Walker Lake.

Huxel (1969) estimated the following recharge components to the Mason Valley hydrographic basin: 1) 3 percent from precipitation that falls on the surrounding mountain ranges; 2) 97 percent from the river and associated agricultural diversions; and 3) less than 0.1 percent from direct precipitation on the valley floor. Along the southern margin of the Site, recharge to the alluvium from the adjacent Walker River occurs as a result of the river losing water through seepage. As an example, visible seepage from the Walker River can be observed on the east highwall of the open pit.

As the river flows northeast past the City of Yerington, the Groundhog Hills, a spur of the Singatse Range, likely attenuates recharge from the Walker River to the alluvium underlying the north half of the Site (recharge from the Campbell Ditch to the alluvial aquifer could also be attenuated by bedrock immediately east of the Groundhog Hills). Percolation from irrigated agricultural fields immediately north of the Site appears to be the dominant source of groundwater recharge in the northern area of the Site (Brown and Caldwell, 2009a).

Although some degree of resistance to vertical flow exists within the alluvial aquifer, created by the depositional layering of sedimentary deposits and the local occurrence of low-permeability layers, some downward migration of mine-related groundwater is likely to have occurred as a result of historic operations at the Site and the influence of concurrent and post-mining agricultural irrigation practices immediately adjacent to the northern margin of the Site. Downward vertical hydraulic gradients have been observed at a number of locations around the northern margin of the Site, as described in the *2009 Annual Groundwater Monitoring Report* (Brown and Caldwell, 2010e).

Based on core samples collected from previous investigations in the Process Areas (Brown and Caldwell, 2005b), the underlying alluvial fan materials consist of finer-grained mud-flow deposits and coarser-grained channel deposits. Depth to bedrock beneath the Process Areas is estimated to be approximately 200 feet bgs, based on borehole logs for Anaconda well WW-10 and recent drilling. The alluvial-bedrock contact deepens towards the north end of the Site to an estimated depth of 600 to 800 feet bgs in the vicinity of the evaporation ponds. Hydrogeologic cross-sections of the Process Areas from the 2004-2005 investigation are provided in Appendix F-3, along with available grain size distributions for representative borehole intervals.

Figure 3-2 presents a potentiometric surface map for the Process Areas based on February (1Q) 2010 groundwater elevations in the shallow hydrostratigraphic zone, which includes data from recently installed monitor wells as part of the RI for select Arimetco Facilities (OU-8). Inclusion of the Arimetco monitor well data has improved our understanding of groundwater flow and hydraulic gradients in the vicinity of the Process Areas. Previously, hydraulic gradients were assumed to be spatially uniform and the groundwater flow direction was interpreted to be to the north-northwest. The Arimetco monitor well data indicate that: 1) hydraulic gradients on the east side of the Process Areas are unchanged; 2) hydraulic gradients in the central and western portions of the Process Areas are smaller in magnitude and suggest a more northwesterly flow direction; and 3) gradients and flow velocities north of the Process Areas are unchanged from the previous conceptual model.

Based on the groundwater elevations shown on Figure 3-2, groundwater flow velocities were calculated using Darcy's Law (Charbeneau, 2000; equations 2.1.1 and 2.1.10), reproduced below as Equation 1:

$$|v| = \frac{1}{n_e} K_H i$$

where:

- $|v|$ = magnitude of groundwater velocity
- n_e = effective porosity of the shallow aquifer
- K_H = horizontal hydraulic conductivity of the shallow aquifer
- i = hydraulic gradient

Based on the information presented in the *Second-Step Hydrogeologic Framework Assessment Data Summary Report* (Brown and Caldwell, 2008), the following aquifer parameters were selected to represent the shallow aquifer in the vicinity of the Process Areas: 1) an effective porosity of 0.30; and 2) a range of horizontal hydraulic conductivity values from 6 to 20 feet/day (ft/d). Because groundwater flow directions and hydraulic gradients vary spatially in the vicinity of the Process Areas, four locations on Figure 3-2 were identified to represent the range of potential gradients and groundwater velocities. Hydraulic gradients for the four locations were estimated by dividing the change in groundwater elevation between two points by the measured distance between the points perpendicular to the water level contours. Estimated hydraulic gradients for the four locations are:

1. 0.00194 feet per foot (ft/ft)
2. 0.00141 ft/ft
3. 0.00094 ft/ft
4. 0.00194 ft/ft

Using these gradients, the following groundwater velocity (i.e., travel time) values were calculated for the four representative locations:

1. 0.04-0.13 ft/d (15-47 feet/year or ft/yr)
2. 0.03-0.09 ft/d (11-33 ft/yr)
3. 0.02-0.06 ft/d (7-22 ft/yr)
4. 0.04-0.13 ft/d (15-47 ft/yr)

Vectors drawn on Figure 3-2 represent both the direction and the relative magnitude of groundwater velocities in the shallow alluvial aquifer beneath the Process Areas and adjacent Site features. Given that location no. 2 represents flow conditions immediately beneath the Process Areas, and its gradient and velocity estimates are within the mid-range of the four locations, the gradient of 0.00141 and velocity of 0.03-0.09 feet per day (ft/day) (11-33 ft/yr) best represents groundwater travel times. Assuming gradients and velocities have generally remained consistent during the 32 years since Anaconda ceased operations in 1978, these values suggest groundwater has migrated between 350 and 1,050 feet in a north-northwest direction beneath the Process Areas.

3.2 Contamination and Affected Media

This section describes known and potential sources of chemicals in the Process Areas, chemical release mechanisms, chemical transport pathways for media found within the Process Areas, and the spatial distribution of chemicals of interest in Process Areas soils and groundwater. The chemical sources, release mechanisms, transport pathways, and potential routes of human and ecological exposure for the Site are summarized in the revised CSM (Brown and Caldwell and Integral Consulting, 2009). For the purposes of this Vadose Zone Work Plan, the term ‘mine-related chemicals’ are chemicals that have been concentrated in soils or groundwater by past operational practices and the term ‘mine-related groundwater’ is groundwater that appears to have elevated concentrations of iron, sulfate and other chemicals resulting from past operations.

3.2.1 Potential Sources and Release Mechanisms

Based on the information presented in Sections 2.1 and 2.2, a brief summary of sources and potential release mechanisms of chemicals to Process Areas soils is provided below:

- Seepage of ore beneficiation solutions from conveyances and ponds – Solutions (pregnant or spent) conveyed in lined or unlined ditches, or in pipes, and solutions stored in lined or unlined ponds, may have been released at a number of locations. As discussed below, a current example may be seepage from one of the Arimetco Phase III (4X or South) heap leach pads.
- Spilling of sulfuric acid solutions – Sulfuric acid may have been released during filling or circulation via piping and pumps within the acid plant and the precipitation plant area, as well as conveyances between these components.
- Seepage of calcines – Calcines conveyed via the calcine ditch to the evaporation ponds may have been released.
- Releases of laboratory materials – A drain line that leads to a Dry Well (one of five identified or suspected Dry Wells in the Process Areas) is portrayed on historical maps of the on-site laboratory (CH2M Hill, 2010). Releases of laboratory materials may have occurred via this line. The location of this Dry Well is shown on Figure 3-3.
- Releases of ore beneficiation solutions, waste fluids, and/or water via Dry Wells – Four additional known or suspected Dry Wells in the Process Areas were identified in a technical memorandum prepared on behalf of EPA (CH2M Hill, 2010). One suspected Dry Well is located in Area 1 west of the grease storage shop and south of the former fuel tank storage. Other Dry Wells are located in Area 3 adjacent to the pump house at the northwest end of the Leach Vats, in Area 4 reportedly adjacent to the former cooling tower north of the Solution Tanks, and in Area 5 on the southwest side of the Precipitation Plant at the strong solution influent to the iron launders. The known or suspected locations of these Dry Wells are shown on Figure 3-3 (from CH2M Hill, 2010).
- Releases of motor and fuel oil and gasoline – Spills of oils and fuels may have occurred during fueling of mine work vehicles via the mobile fueling truck and during maintenance of work vehicles. Maintenance activities may have also included the use of degreasers and soaps, which could have also been released. Releases may have also occurred via the floor drain located in the Truck Shop. Wash waters and other liquid wastes may have drained to the Upper and Lower Truck Sludge Ponds.
- Leaks or spills from oil and fuel storage tanks – Underground and aboveground storage tanks were used to store oil and fuel. Leaks from tanks and at filling stations may have occurred over time and spills may have occurred during filling operations where tanks were or are located.
- Leaks and spills from stored materials – Stored lubricants, oils, solvents, and transformers may have leaked in cases where the integrity of the containers/equipment was compromised.

3.3 Contaminant Migration Pathways

General transport mechanisms for mine-related chemicals from primary impacted media to secondary and tertiary impacted media are described below.

3.3.1 Surface Soil

Chemicals released directly to surface soils as a result of former mining and milling activities, or unplanned releases, may be transported by wind and surface water runoff. The presence of natural or man-made physical barriers, such as vegetation, concrete slab pads and foundations, and wind barriers (buildings walls, berms, etc) will inhibit or reduce the transport of particles as wind-blown dust. Particulates or fugitive dust transported by wind may be deposited and may accumulate in downwind areas. Areas of dust accumulation may become secondary sources of chemicals to sub-surface soil and groundwater via leaching and percolation. The migration of inorganic and organic chemicals may be influenced by the chemical and physical properties of the soils (EPA, 2002).

3.3.2 Vadose Zone Infiltration

Infiltration of ore beneficiation solutions into the vadose zone, with the potential to source chemicals to groundwater is a potential release mechanism that likely ceased when operations associated with Anaconda/ARC ownership ended in 1978. The elimination of a driving head at the surface and increased soil moisture storage capacity resulted from the past evaporation of solutions on the surface and ‘drying-out’ of surface mine units (i.e., Seitz et. al., 1982). Subsequent operators at the Site (e.g., Copper Tek and Arimetco) re-established localized surface head conditions within or adjacent to the Process Areas (e.g., Mega Pond) where heap leach solutions may have resulted in the flux of mine-related chemicals to groundwater.

Geochemical mechanisms such as mobilization and attenuation may modify the concentration of chemicals in percolating ore beneficiation solutions or leachate through soils or the underlying vadose zone. There is the potential for precipitation to leach (mobilize) constituents from mine unit materials. Conversely, some chemicals in meteoric water infiltrating through mine units may be attenuated (e.g., via adsorption). Salts and metals may be concentrated near the surface

via evaporative reflux in the arid environments at the Site. Development of a conceptual model for the fate and transport of residual mine-related chemicals within the vadose zone underlying the Process Areas, and the potential for such chemicals to be sourced to groundwater under existing or anticipated conditions is required to develop vadose zone characterization activities, as described in the FSAP (Section 5.0), and support predictive hydraulic modeling.

The conceptual vadose zone model for the distal alluvial fan materials underlying the Process Areas is, in part, based on the grain size distribution data provided in Appendix D-1 of the draft RI Work Plan (Brown and Caldwell, 2007a) for specific intervals of the boreholes that were drilled and logged during previous investigations. The grain size distributions for PA-GW-14 (samples from 25 and 53 feet bgs), PA-GW-17 (samples from 15 and 54 feet bgs), and PA-GW-21 (samples from 16 and 62 feet bgs) suggest that the vadose zone is relatively homogeneous in character beneath the entire extent of the Process Areas. The sample intervals selected for the preliminary grain size analyses represent both silty sand and sandy lean clay soil classification types, as logged in the field.

Despite these generalized conditions, the vadose zone conceptual model should recognize the potential for preferential and fast seepage to the underlying alluvial aquifer that result from local heterogeneities. Preferential flow is defined as flow that occurs in a non-volume averaged fashion along localized, preferential pathways, by-passing a fraction of the porous space. In heterogeneous soils, such flow may occur along root channels, burrows and soil fissure and cracks, as well as at geologic heterogeneities such as fractures or discontinuities in caliche layers.

Heterogeneities may be created by depositional conditions, diagenesis of sediments, faulting, fracturing, and differential weathering mechanisms. The heterogeneity of soils and sediments on different scales combined with non-uniform areal precipitation and run-off are primary causes of the phenomenon of multi-scale flow (slow matrix versus fast preferential) in the vadose zone (Looney and Falta, 2000). A conceptual model for water flow in heterogeneous soils is complicated by the following three factors (Looney and Falta, 2000):

- The contrasts in permeability of soils at different locations and depth in the system may be extreme, and very localized (e.g., on the scale of inches);
- The geometry of water flow depends strongly on the interconnection or connectivity of a preferential flow zone network, which makes the confirmation through field monitoring difficult, and very costly and time-consuming at best; and
- Point measurements, typically obtained from field monitoring, can not reveal complex processes that result from the interaction of features at many different scales.

Unsaturated water flow in the vadose zone is controlled by the unsaturated hydraulic conductivity and the hydraulic gradient. Under gravity drainage, the hydraulic gradient is typically considered to be a unit gradient (i.e., 1). Under this condition the magnitude of the unsaturated flux is determined by the unsaturated hydraulic conductivity with the unsaturated hydraulic conductivity being a function of the volumetric water content (θ) of the soil (i.e., $K(\theta)$). The direction of the unsaturated flow flux is determined based on the matric suction or negative pore water pressure (Ψ) value with moisture moving from less negative values (lower suction) to more negative values (higher suction).

Characterization of unsaturated soils requires that the relationship between pore-water pressure and the soil θ value be represented by the soil-water characteristic curve (SWCC). The most common approach to determine unsaturated hydraulic conductivity is to develop a SWCC from either field or laboratory data, and then use an analytical equation that relates θ for a given soil to the unsaturated hydraulic conductivity (e.g., van Genuchten, 1980). Values for θ and Ψ are affected by the texture and structure of soils. Field and laboratory characterization efforts should focus on these primary drivers under ambient flux conditions, and the four vadose depths moisture profile zones for (semi-) arid climates (Looney and Falta, 2000):

1. Land surface or boundary zone which is directly and immediately affected by episodic climatic events including precipitation, temperature, and wind. This zone extends from the surface to approximately two feet bgs.
2. An intermediate zone extending from the boundary zone to as much as 30 feet bgs. This zone may attenuate land surface climatologic effects, particularly in the semi-arid west, and will act as a short-term storage zone for infiltrated precipitation.

3. A deep vadose zone of virtually constant moisture content, in which the hydraulic gradient is unity, i.e. 1, and there is annual downward water flow. This zone is estimated to extend from the intermediate vadose zone to the capillary fringe above the water table, which may be up to 10 feet in thickness.
4. A capillary fringe zone above the water table.

Land Surface or Boundary Zone

This zone controls the amount of precipitation that infiltrates into the sub-surface versus the amount of precipitation that becomes runoff. The hydrologic behavior of this zone can vary seasonally dependent on precipitation intensity and other climatic factors such as temperature, wind and humidity. Measuring and/or mathematically representing the soil surface boundary condition is one of the most challenging tasks in unsaturated zone hydrology. Depending on surface conditions, soil water may be draining, wetting or drying. Most of the dynamics of soil moisture movement occur in this zone and an accurate understanding and measurement of fluxes across this zone is crucial to measuring site-specific fluxes to the water table.

Near-Surface or Intermediate Zone

This zone is much less dynamic than the boundary zone, and tends to attenuate the climatologic events that occur at the soil surface. It can have seasonally different flux rates and direction depending on climatic conditions. For example, a net positive flux into the deeper soil zone may occur in the winter months due to low potential evaporation rates, whereas, in the summer there may be a flux out of the near-surface soil zone due to high potential evaporation rates. The thickness of this zone can vary due to climatic conditions and soil properties.

Deep Vadose Zone

This zone is largely insulated from climatic effects at the land surface, or fluctuating water tables caused by larger scale regional hydrologic stresses. It is characterized by largely downward movement of any seepage that infiltrates from the land surface and manages to migrate through the intermediate zone without being extracted via evapotranspiration. The magnitude, timing and location of infiltration through the deep zone will result from the geotechnical properties of, and localized heterogeneities within, the alluvial fan materials.

Past infiltration of mine-related chemicals from Process Areas components through the vadose zone to groundwater may have occurred in localized areas where sufficient volumes of ore beneficiation or other solutions were present to create the necessary hydraulic head. However, based on the low precipitation rates observed at the Site (i.e., effectively zero recharge rates to groundwater from precipitation; Huxel, 1969) and high evaporation rates, very little infiltration under existing conditions would be expected.

Groundwater

Mine-related groundwater that may have been sourced from Process Areas components, or from other hydraulically up-gradient surface mine units (e.g., Anaconda or Arimetco leaching facilities), may migrate to other areas of the Site or flow off-Site. Potential physical and chemical pathways are discussed in more detail in the *Site-wide Groundwater (OU-1) Remedial Investigation Work Plan* (Brown and Caldwell and Integral Consulting, 2007). Additional groundwater data are being collected to improve the CSM for groundwater conditions pursuant to the *2010 Groundwater Monitor Well Work Plan -Revision 2* (Brown and Caldwell 2010c).

Surface Water

Erosion and leaching of surface mine units due to surface water runoff (e.g., storm water events or snowmelt) may result in the deposition of chemicals in other down-gradient locations. Storm water may potentially accumulate in topographically low areas, as well as the calcine ditch and other ditches. Accumulation of water in topographically low areas may occur where otherwise, during dry times of the year, soil would be exposed. Areas of surface water accumulation may become secondary sources of chemicals to sub-surface soil and groundwater via leaching and vadose zone infiltration.

Radiation

In addition to migration of chemicals from their sources to other media, radiation may exist where radiochemicals occur in soils, surface water and groundwater, or where such media have contacted buildings, equipment, piping, structures or other features. Transport of the material may have occurred, or may be occurring, by any of the transport pathways described above.

External radiation from materials (e.g., buildings, structures, piping or weathered pipe scale, etc.) is geometrically attenuated even with no interposed shielding materials, (i.e., inverse square law). The effects of elevated levels of external radiation are limited to within a few meters, typically less than 5 meters, and often less than 1-2 meters from the source (Cember, 1996).

3.4 Conceptual Model Summary

The Process Areas are located above unconsolidated deposits consisting of alluvial fan sediments up to 200 feet thick that overlie granitic and volcanic bedrock. The saturated portion of the unconsolidated alluvial fan deposits beneath the Process Areas is primarily recharged by seepage from the Walker River and, to a lesser degree, precipitation that falls on the Singatse Range that migrates from the mountain block to the Site. Per Huxel (1969), less than 0.1 percent of total recharge to the Site, including the Process Areas, results from infiltration of precipitation that falls directly on the valley floor (i.e., on the ground surface of the Process Areas).

During ore beneficiation and related operations, pregnant or waste solutions may have escaped containment, or achieved sufficient head conditions in unlined conveyance or storage facilities, to source mine-related chemicals through the vadose zone to groundwater. Although the stratification of the alluvial fan deposits beneath the Process Areas may provide some resistance to vertical flux through the vadose zone to the underlying alluvial aquifer, downward vertical migration of mine-related chemicals may have occurred at some locations. Media potentially impacted by mine-related chemicals include soils and groundwater. Potential sources and mechanisms for release of chemicals to Process Areas soils include the following:

- seepage of pregnant and spent solutions conveyed through the Process Areas in lined/unlined ditches and pipes, as well as solutions stored in lined/unlined ponds;
- spills of sulfuric acid solutions conveyed by pumps through piping at the Precipitation Plant as well as conveyances to that area from the acid plant;
- seepage of calcines conveyed to the evaporation ponds along the Calcine Ditch;
- releases of ore beneficiation solutions, acid solutions, laboratory waste materials, and water via multiple Dry Wells located throughout the Process Areas; and
- releases, spills, or leaks of motor oil, fuel oil, and gasoline from storage tanks, filling stations, and vehicles, and maintenance activities.

Mine-related chemicals released to surface and sub-surface soils could potentially result in the following pathways:

- Chemicals released to surface soils have the potential to be transported directly by wind and surface water runoff, although the presence of natural and man-made barriers is likely to inhibit air-borne transport at many locations.
- Storm water runoff has the potential to erode and leach chemicals from soils and mine wastes, which may subsequently be transported to and deposited in downstream locations (e.g., the Calcine and East Solution Ditches). Deposition and ponding in topographically low areas may have released chemicals via leaching and infiltration.
- Historical infiltration of solutions into had the potential to release chemicals to deeper soil intervals and groundwater. Subsequent elimination of the driving head at the ground surface and drying of soils have resulted in increased soil moisture storage capacity.
- Infiltration of precipitation may continue to leach chemicals from Process Areas soils, potential mobilization of chemicals from soils to deeper vadose zone intervals or groundwater. However, this pathway may be limited based on observed water-balance and evaporative flux conditions that occur in the arid environment at the Site.
- Observed current groundwater impacts may have resulted from pregnant or spent solutions within the Process Areas, from contaminated Process Areas soils, or from up-gradient sources (Anaconda and/or Arimetco facilities).
- Mine-related chemicals in groundwater have migrated, and may continue to migrate, in a down-gradient direction at calculated rates of approximately 11 to 33 feet per year.
- Radiometric surveys indicate the presence of TENORM within the Process Areas (e.g., scale/sediment occurrences within transite pipe and soils) and radiochemicals in groundwater.

SECTION 4.0

DATA GAPS AND DATA QUALITY OBJECTIVES

This section of the Vadose Zone Work Plan discusses the data gaps that will be filled to allow decision makers for the Site to assess the past, present or future potential sourcing of mine-related chemicals to underlying groundwater through the unsaturated soil profile beneath the Process Areas. These data gaps are represented by the problem statements presented in the DQOs for vadose zone and groundwater characterization activities, and the planned investigation of sub-surface Dry Wells and utility pipelines. The rationale for the selection of ‘worst-case’ locations to be investigated relies on the information presented in Section 2.0 (Site historical information and previous investigations) and Section 3.0 (CSM), and the information presented in Appendices D and E. These locations appear to have: 1) had the greatest potential to source chemicals to soils and underlying groundwater from past operations; and 2) the greatest potential to source chemicals to these media under existing or anticipated future climate conditions.

Locations of proposed monitor well installations are based on observations of current groundwater conditions beneath the Process Areas described in Sections 2.0 and 3.0 and ARC’s intent to utilize a sub-set of the vadose zone boreholes for groundwater characterization activities and monitor well installations. ARC recognizes that additional groundwater monitor wells will be installed within the Process Areas boundary, at different depths at one location and/or at other locations to be selected during future scoping of the revised Site-wide Groundwater OU RI Work Plan or as a subsequent phase of the Process Areas OU RI Work Plan (see Section 1.3).

In addition to identifying Dry Well locations in the Process Areas, the sub-surface utility investigation will provide the basis for additional soil sampling associated with these features as part of a subsequent phase of the Process Areas RI. As described in Section 5.0, ARC plans to conduct the sub-surface utility investigation prior to the drilling of characterization boreholes.

4.1 Data Quality Objectives

The DQOs developed for this Vadose Zone Work Plan are intended to ensure that reliable data are acquired for decision making by the project management team described in Section 1.4. A systematic seven-step planning approach outlined in the EPA quality assurance document *Guidance on Systematic Planning Using the Data Quality Objective Process* (EPA, 2006) is used to establish performance or acceptance criteria, which serve as the basis for designing a plan for collecting data of sufficient quality and quantity. The DQO process consists of the following seven iterative steps:

- Step 1: State the Problem
- Step 2: Identify Study Goals
- Step 3: Identify Information Inputs
- Step 4: Define the Boundaries of the Study
- Step 5: Develop an Analytical Approach
- Step 6: Specify Performance or Acceptance Criteria
- Step 7: Develop the Plan for Obtaining the Data.

The DQOs for this Work Plan, and associated steps towards obtaining the appropriate data, are summarized in Table 4-1.

4.2 Sub-Surface Utility and Dry Well Investigations

Spectrum Geophysics of Burbank, California will conduct a comprehensive sub-surface investigation of the sub-surface lines depicted on Figure 4-1 (a sub-set of the utility and solution conveyance features shown on Figure 2-2), and the Dry Wells shown on Figure 3-3, to: 1) locate detectable Dry Wells within a 200-foot radius of the five locations identified by CH2M Hill (2010); 2) determine the geometry of identified underground utilities; and 3) assess the condition of camera-accessible sub-surface utility lines. As described below, Spectrum Geophysics will employ a variety of utility locating methods to investigate these sub-surface features.

Table 4-1. Data Quality Objectives Summary						
Step 1	Step 2	Step 3	Step 4	Step 5	Step 6	Step 7
Problem Statement	Identify Study Goals	Identify Information Inputs	Study Boundaries	Develop the Analytical Approach	Specify Performance or Acceptance Criteria	Develop the Plan for Obtaining Data
<p>The geometry and condition of sub-surface pipelines and Dry Wells that may have been used to convey or dispose of ore beneficiation solutions and other waste streams are not completely known.</p> <p>Under existing or anticipated climate conditions at the Site, the potential for impacted Process Areas soils (i.e., alluvial fan materials) to source chemicals to the underlying alluvial aquifer is not known.</p> <p>Groundwater flow and chemical conditions beneath the Process Areas are not completely known.</p>	<p>Using available technology and industry standard methods, investigate the geometry, depths and (if possible) assess the condition of the sub-surface pipelines and Dry Wells.</p> <p>Characterize the chemical condition of alluvial fan materials beneath the Process Areas, from the surface to the base of the unsaturated (vadose) zone above the underlying alluvial aquifer. The majority of vadose zone characterization locations represent ‘worst-case scenarios’ for potential current or future sourcing of chemicals to groundwater.</p> <p>Characterize the unsaturated hydraulic properties of the alluvial fan materials in four vadose sub-zones (land surface, intermediate vadose, deep vadose and capillary sub-zones).</p> <p>Characterize saturated alluvium and bedrock conditions at three locations.</p> <p>Develop conceptual and numerical models of the vadose zone beneath the Process Areas based on the characterization results. Simulate vadose zone flux and seasonal moisture movement, and the average net flux (if any) to the water table under representative climate conditions.</p>	<p>Geophysical survey results using the methods described in Appendix H.</p> <p>Lithologic, chemical, hydraulic and geotechnical data from representative alluvial fan materials beneath the Process Areas.</p> <p>Vadose zone numerical modeling results, including model sensitivity analyses.</p> <p>Groundwater chemical data from zonal samples and existing and new monitor wells.</p>	<p>The outline of the main Process Areas shown in Figure 1-2 defines the two-dimensional extent of the sub-surface utility, vadose zone and groundwater investigations.</p> <p>The vertical extent of the vadose zone investigation extends from the surface to capillary sub-zone above the water table, which is approximately 100 feet bgs in the Process Areas.</p> <p>The vertical extent of the groundwater investigation extends from the top of the water table to a depth of 50 below the alluvium-bedrock, contact.</p> <p>The temporal boundary for the characterization activities described in this Vadose Zone Work Plan is from September 2010 through September 2011.</p>	<p>Lithologic information from core logging and grain-size distribution analyses.</p> <p>Laboratory analyses of metals and radiochemicals in core samples of alluvial materials.</p> <p>Leachate (MWMP) testing of alluvial samples from core samples, and laboratory analyses leachate chemistry (i.e., metal and radiochemical concentrations).</p> <p>Hydraulic properties for alluvial fan materials in the four vadose zone sub-zones:</p> <ul style="list-style-type: none">Grain size distribution including hydrometer for clay percentage (ASTM D-422)Moisture content (ASTM D2216)Bulk density (ASTM D2937)Atterberg Limits (ASTM D4318)7-point SWCC including the saturated hydraulic conductivity (ASTM D2355) <p>Laboratory analyses of metals and radiochemicals in zonal and monitor well samples from the alluvial aquifer. Zonal samples collected from the water table to bedrock.</p>	<p>Acceptance of chemical analytical results will be based on verification and validation criteria specified in the Site-Wide QAPP (Revision 5).</p> <p>Acceptance of geotechnical laboratory results per the American Society of Testing and Materials (ASTM) standards or other applicable Site-specific Applicable or Relevant and Appropriate Requirements (ARARs) identified by ARC and EPA.</p>	<p>The investigation consists of 13 vadose zone characterization locations and three groundwater zonal sampling and monitor well locations based on the information presented in this Vadose Zone Work Plan.</p> <p>Vadose zone characterization locations shown on Figure 4-2 have been identified on the following rationale:</p> <ul style="list-style-type: none">Areas associated with known occurrences of mine-related groundwater and/or mine-related chemicals in Process Areas soils that may have been subjected to sufficient quantities of solutions during historic operations (i.e., ‘worst-case’ locations);Areas with a moderate-to-high potential for meteoric water infiltration due to relatively permeable surface soil conditions, the likelihood of recent ponding and localized vegetation occurrences that would likely be supported by sufficient soil moisture content: andAreas that appear to have a low potential for infiltration. <p>Groundwater zonal sampling and monitor well installations at the locations shown on Figure 4-3 have been identified based on the need to have a broader distribution of monitor wells in the Process Areas and the rationale presented in Table 4-3.</p>

Based on the information obtained from the Site archives, the approximate locations of the Dry Wells will be staked in the field in advance of the geophysical investigations (ARC anticipates that the staking will be performed with oversight from an EPA representative or contractor). A 200-foot radius (an approximate 3-acre area) around each staked location will then be investigated using high sensitivity metal detection (EM-61), terrain conductivity (EM-31) and ground penetrating radar (GPR).

As presented in Appendix H, the following equipment will be used to locate detectable metallic and nonmetallic structures:

- Geonics (EM-61 High Sensitivity Metal Detection
- Geonics EM-31 terrain conductivity meter
- Sensors and Software ground penetrating radar (GPR) unit
- RD electromagnetic utility-locating transmitter w/ matched receiver
- Fisher TW-6 M-scope – shallow focus metal detector

In non-metallic piping, cleanouts and drains that are accessible, a micro transmitter (sonde) attached to fiberglass probes will be inserted into openings and the transmitted signal from the sonde will be identified on the ground surface using a hand held receiver. The length of probe inserted into the pipe depends on the diameter, condition and construction of the pipe. Typically access is required every 100-250 feet along the piping. In addition, a camera will be inserted into accessible pipelines to determine the construction and general condition of the utility lines.

The results of the Dry Well geophysical investigations will be used to confirm the presence or absence of the Dry Wells shown on Figure 3-3, and precisely locate the associated vadose zone characterization boreholes shown on Figure 4-2 for the confirmed Dry Well locations. Geophysical results for the sub-surface utility investigation will be used to design a future phase of soil investigations in the Process Areas.

4.3 Vadose Zone Characterization Locations

Thirteen boreholes are planned for the characterization of vadose zone conditions beneath the Process Areas, as shown on Figure 4-2. One of the potential Dry Well locations (Dry Well #4) identified by CH2M Hill (2010) is based on anecdotal information (i.e., no information for this Dry Well was found in the Site historical archives). If this Dry Well cannot be located by the sub-surface geophysical methods described in Section 4.2, a characterization borehole specifically targeted at the Dry Well #4 location will not be drilled.

In addition to the vadose zone characterization boreholes (PA-VZ-1, PA-VZ-2, PA-VZ-5, PA-VZ-7, and PA-VZ-11) associated with the five identified Dry Well locations, the eight remaining proposed boreholes are located in ‘worst-case’ soil impact areas, as described in Section 2.2.1 and illustrated in Appendices D and E. The locations for PA-VZ-3, PA-VZ-4, PA-VZ-6, and PA-VZ-9, PA-VZ-10, PA-VZ-12, and PA-VZ-13 are shown on Figure 4-2. The soil impacts described in Section 2.2.1 that resulted in selection of these proposed borehole locations include: 1) the highest concentrations of selected metals (e.g., arsenic, iron, thallium, thorium, and uranium) and radiochemicals (radium-226 and radium-228) reported in previous Process Areas soil samples; and 2) chemical concentration trends that increase with depth for selected metals (cadmium, copper, molybdenum, selenium, thorium, and uranium) and the two radiochemicals.

A number of these borehole locations with radiochemical impacts are consistent with the START Report (EPA, 2008). PA-VZ-8, shown on Figure 4-2, was located to address a data gap (i.e., an absence of sub-surface soil samples where the maximum copper concentration was reported in a surface soil sample adjacent to the Precipitation Plant sump). Table 4-2 presents the rationale for each vadose zone characterization borehole.

Table 4-2. Proposed Vadose Zone Characterization Locations

Source Characteristics	Soil Impacts	Location
<p>Area 3 – Leach Vats</p> <ul style="list-style-type: none"> Eight concrete vats used for sulfuric acid leaching of crushed copper ore. Acid leaching solution percolated through crushed ore in each vat, followed by application of a rinse solution Two 2,000-gpm variable pumps recirculated solution through leach vats 	<p>Leach Vats:</p> <ul style="list-style-type: none"> Elevated Cd (0.37-0.44 mg/kg) throughout 9.0-25.0 ft bgs at PA-P15 Elevated Mo (3.9-9.2 mg/kg) from 14.0-25.0 ft bgs at PA-P15 Elevated Ra-228 (2.2 and 2.9 pCi/g) from 9.0-10.0 ft bgs at PA-P15 START radiation assessment did not address areas immediately surrounding the leach vats 	PA-VZ-3
<p>Area 4 – Solution Tanks and Solution Spill Sump</p> <ul style="list-style-type: none"> Three tanks used for short-term storage of pregnant acid leach solutions from Leach Vats awaiting precipitation Solution spill sump between Leach Vats and Solution Tanks 	<p>Solution Tanks and Solution Spill Sump:</p> <ul style="list-style-type: none"> Elevated Cu (3,200 mg/kg), Ra-226 (4.3 pCi/g), Th (19.5 mg/kg), and U (11 mg/kg) at PA-DD10, 0.5-1.0 ft bgs Elevated Cu (430 mg/kg at 0.5-2.5 ft and 500 mg/kg at 8.5-10.0 ft bgs), Ra-226 (13.7 pCi/g at 0.5-2.5 ft bgs), Ra-228 (5.5 pCi/g at 0.5-2.5 ft bgs), Th (40.2 mg/kg at 0.5-2.5 ft bgs), and U (6.5 mg/kg at 0.5-2.5 ft bgs) at PA-FF3 Negative ABP (-3 t/kt) at PA-FF3, 10 ft bgs Elevated Cu at PA-FF4 from 0.5-2.5 ft bgs (3,500 mg/kg) down to 10.0-20.0 ft bgs (690 mg/kg) Elevated concentrations of additional metals (e.g., As, Cd, Fe, Pb, Ni, Se, and Zn) from 0.5-1.0 ft bgs at PA-DD10, from 0.5 to 10.0 ft bgs at PA-FF3, and from 0.5-5.0 ft bgs at PA-FF4 START radiation assessment indicates measurements at location of boring PA-FF3 adjacent Solution Spill Sump are in the range of 20,829-48,375 cps (i.e., measurements above 20,828 cps represent potential areas of surface contamination above the site-specific action level of 3.79 pCi/g Ra-226), consistent with Ra-226 results for PA-FF3 	PA-VZ-4
<p>Area 5 – Precipitation Plant Sump:</p> <ul style="list-style-type: none"> 25 years of operation (ca 1953-1978) Recirculated 700-900 gpm pregnant solution 15-25 g/L copper ; 4-5 g/L sulfuric acid Sump extends 20 ft below grade, likely leaked DTW below sump = 78 ft 	<p>Precipitation Plant Sump:</p> <ul style="list-style-type: none"> Max. Cu (44,000 mg/kg) at 0.5 ft bgs at PA-EE6, Elevated As (63 mg/kg), Cd (1.3 mg/kg), Pb (170 mg/kg), Mo (6 mg/kg), Ni (31 mg/kg), Se (4.1 mg/kg), U (22 mg/kg), and Zn (270 mg/kg) at 0.5 ft bgs at PA-EE6 Negative ABP value (-12 t/kt) at PA-EE20, 30 ft bgs START radiation assessment indicates measurements at northwest end of Precipitation Plant adjacent sump are in the range of 20,829-48,375 cps (i.e., measurements above 20,828 cps represent potential areas of surface contamination above the site-specific action level of 3.79 pCi/g Ra-226) 	PA-VZ-8
<p>Area 5 – Precipitation Plant</p> <ul style="list-style-type: none"> Fifteen concrete launders filled with low-grade scrap iron used to precipitate copper from sulfuric acid leach solution pumped to the Precipitation Plant from the Leach Vats In addition to launders, Precipitation Plant included pumps, sumps, and associated piping conveyed solutions along outside perimeter of the launders 	<p>Precipitation Plant:</p> <ul style="list-style-type: none"> Elevated Cu (1,100 and 340 mg/kg) from 1.0-2.0 and 29.5 to 30.5 ft bgs at PA-EE19 and 660 mg/kg from 0.5 to 1.5 ft bgs at PA-EE7 Max. Ra-226 (18 pCi/g) at Area 4 location PA-DD5 (1 ft bgs near pipe trench exiting Solution Tanks) and elevated Ra-226 (3.7 and 4.0 pCi/g) from 1.0-2.0 ft bgs at PA-EE19 and 0.5-1.5 ft bgs at PA-EE7 Elevated Ra-228 (2.4-2.9 pCi/g) from 19.5-30.5 ft bgs at PA-EE19 Elevated U (12.1 mg/kg) from 29.5 to 30.5 ft bgs at PA-EE19 Elevated Cd (0.38-1.1 mg/kg) from 1.0-5.5 and 24.5-30.5 ft bgs, highest values observed in the interval from 20.5-30.5 ft bgs Elevated Se (1-2.5 mg/kg) from 0.5-1.5 ft bgs at PA-EE7 and from 1.0-2.0 ft bgs at PA-EE19 Negative ABP value (-11 t/kt) at PA-EE19, 25 ft bgs START radiation assessment indicates measurements in vicinity of Precipitation Plant Pipe Trench Dry Well are mostly in the range of 20,829-48,375 cps (i.e., measurements above 20,828 cps represent potential areas of surface contamination above the site-specific action level of 3.79 pCi/g Ra-226) 	PA-VZ-6

Table 4-2. Proposed Vadose Zone Characterization Locations		
Source Characteristics	Soil Impacts	Location
<p>Area 7 - Calcine Ditch – Downstream End:</p> <ul style="list-style-type: none"> 25 years of operation (ca 1953-1978) 750 gpm of slurry conveyed along unlined ditch Calcines from Acid Plant combined with spent solution from Precipitation Plant 	<p>Calcine Ditch – Downstream End:</p> <ul style="list-style-type: none"> Elevated Cu (300-1,600 mg/kg) from 14.0-15.0 ft bgs at PA-WW1, from 19.0-20.0 ft bgs at PA-WW2 and PA-WW3, and from 9.0-10.0 ft bgs at PA-WW4 Elevated Ra-226 (3.4-4.6 pCi/g) from 9.0-10.0 ft bgs at PA-WW1 and PA-WW2 and from 4.0-10.0 ft bgs at PA-WW3 Elevated Ra-228 (3.5-20.0 pCi/g) from 9.0-15.0 ft bgs at PA-WW2 and from 9.0-10 ft bgs at PA-WW4 Elevated Th (20.5-172 mg/kg) from 9.0-15.0 ft bgs at PA-WW2 and from 9.0-10 ft bgs at PA-WW4 Elevated U (4.6-32.9 mg/kg) from 9.0-20.0 ft bgs at PA-WW2 and PA-WW3 and 9.0-10.0 ft bgs at PA-WW4 Elevated concentrations of additional metals (i.e., As and Se) in selected samples from 4.0-20.0 ft bgs at PA-WW2, PA-WW3, and PA-WW4. Also, maximum concentrations of As (410 mg/kg), Fe (95,000 mg/kg) and Tl (40 mg/kg) from 9.0-10.0 ft bgs at PA-WW4 Most negative ABP (-64 t/kt) at PA-WW4, 10 ft bgs Elevated TPH-mo (100 mg/kg) at PA-WW3, 5 ft bgs START radiation assessment indicates measurements from several locations at downstream (north) end of Calcine Ditch in the range of 20,829-48,375 cps (i.e., measurements above 20,828 cps represent potential areas of surface contamination above the site-specific action level of 3.79 pCi/g Ra-226). 	PA-VZ-13
<p>Area 7 - Calcine Ditch – Upstream Portion:</p> <ul style="list-style-type: none"> 25 years of operation (ca 1953-1978) 750 gpm of slurry conveyed along unlined ditch Calcines from Acid Plant combined with spent solution from Precipitation Plant 	<p>Calcine Ditch – Upstream Portion:</p> <ul style="list-style-type: none"> Elevated Cu (430-2,400 mg/kg) from 3.5-10.0 ft bgs at PA-WW7 and PA-WW8, and from 3.5-15.0 ft bgs PA-WW9 Elevated Cd (0.45 and 0.38 mg/kg) from 14.0-15.0 ft bgs at PA-WW7 and PA-WW8 Elevated Pb (20 and 16 mg/kg) from 14.0-15.0 ft bgs at PA-WW7 and PA-WW8 Elevated Mo (3.7-4.6 mg/kg) from 3.5-5.0 and 14.0-15.0 ft bgs at PA-WW7 and from 14.0-15.0 ft bgs at PA-WW8 Elevated Ra-226 (2.5-6.3 pCi/g) from 3.5-5.0 ft bgs at PA-WW7, PA-WW8, and PA-WW9 Elevated Ra-228 (2.2-8.8 pCi/g) from 14.0-20.0 ft bgs at PA-WW7, from 9.0-20.0 ft bgs at PA-WW8, and from 19.0-20.0 ft bgs at PA-WW9 Elevated Se (4.5-10.0 mg/kg) from 3.5-20.0 ft bgs at PA-WW7 and PA-WW8 and from 3.5-15.0 ft bgs at PA-WW9 Elevated Th (30.6-87.4 mg/kg) from 14.0-20.0 ft bgs at PA-WW7 and 9.0-20.0 ft bgs at PA-WW8, Elevated U (4.8 mg/kg) from 19.0-20.0 ft bgs at PA-WW7 	PA-VZ-12
<p>Area 9 – East Solution Ditch</p> <ul style="list-style-type: none"> Seepage of process solutions conveyed through 1200 feet of unlined ditch Juncture of East Solution Ditch and Overflow Solution Ditch, both significant unlined ditches 	<p>East Solution Ditch:</p> <ul style="list-style-type: none"> Elevated Cu (400-760 mg/kg) from 0.5-25.0 ft bgs at PA-EEE15, with highest concentrations at depths of 19.0-25.0 feet bgs. Elevated Cu (330-3,100 mg/kg) from 0.5-2.5 ft bgs at multiple additional locations Elevated Ra-226 (2.6-5.7) from 0.5 to 2.5 ft bgs at PA-EEE2, PA-EEE13, PA-EEE14, PA-EEE15, and PA-EEE17 Elevated Ra-228 (2.2-24.9 pCi/g) from selected intervals between 0.5 and 25.0 ft bgs at multiple locations Elevated Th (20.9-241 mg/kg) from 0.5-5.0 ft at PA-EEE2, PA-EEE5, PA-EEE8, PA-EEE11, PA-EEE13, PA-EEE14, and PA-EEE17, and at 13.5-20.0 ft bgs at PA-EEE17 Elevated U (4.3-53.8 mg/kg) from selected intervals between 0.5 and 25.0 ft bgs at multiple locations Elevated concentrations of additional metals (e.g., As, Cd, Pb, Mo, and Se) from 0.5-20.0 ft bgs at multiple locations 	PA-VZ-10

Table 4-2. Proposed Vadose Zone Characterization Locations		
Source Characteristics	Soil Impacts	Location
	<ul style="list-style-type: none"> START radiation assessment indicate measurements along East Solution Ditch are mostly in the range of 20,829-48,375 cps (i.e., measurements above 20,828 cps represent potential areas of surface contamination above the site-specific action level of 3.79 pCi/g Ra-226), with a cluster of elevated readings observed at the juncture of the East Solution Ditch and Overflow Solution Ditch 	
<p>Area 10 – North Low Area</p> <p>W-3 Dump Leach Surge Pond:</p> <ul style="list-style-type: none"> 13 years of operation (1965-1978) Received 400 gpm spent solution from Precipitation Plant then pumped to W-3 Dump Leach Pond extends 6 ft below grade, likely unlined 	<p>W-3 Dump Leach Surge Pond:</p> <ul style="list-style-type: none"> Elevated Cd (0.089-0.64 mg/kg) from 0.5-10.0 ft bgs at PA-KK1, from 0.5-10.0 ft bgs at PA-KK2, and at 0.5-1.5 and 14.0-15.0 ft bgs at PA-KK3 Elevated Ra-228 (4.2 and 5.1 pCi/g) from 9.0-10.0 and 14.0-15.0 ft bgs at PA-KK3 Elevated Se (1.0 mg/kg) from 0.5-1.5 ft bgs at PA-KK3 Elevated Th (27 and 30.2 mg/kg) from 9.0-10.0 and 14.0-15.0 ft bgs at PA-KK3 Negative ABP (-29 t/kt) at PA-HHH8, 25 ft bgs & (-24 t/kt) at PA-HHH16, 25 ft bgs START radiation assessment results for ERGS gamma survey indicate measurements throughout Surge Pond are mostly in the range of 20,829-48,375 cps (i.e., measurements above 20,828 cps represent potential areas of surface contamination above the site-specific action level of 3.79 pCi/g Ra-226), with localized areas of elevated measurements immediately adjacent to northeast, east and south of the Pond 	PA-VZ-9
Dry Wells		
<p>Leach Vat Pump House Dry Well #1:</p> <ul style="list-style-type: none"> EPA identified probable Dry Well located at northeast corner of Leach Vat No. 8 adjacent to Solution Advance Pump House where two 2,000-gpm variable pumps re-circulated solution through leach vats Drain line from pump house leads to a small Dry Well; the area immediately northwest of leach vats also used to stockpile sulfide ore supplied to Sulfide Plant 	<p>Leach Vat Pump House Dry Well #1:</p> <ul style="list-style-type: none"> Elevated Cu (970-3,000 mg/kg) from 4.0-20.0 ft bgs at PA-P19 Elevated Cd (0.38-0.57 mg/kg) within interval from 4.0-25.0 ft bgs at PA-P19, PA-YY1, and PA-YY2 Elevated Ra-228 (2.8 and 3.3 pCi/g) at 4.0-5.0 and 9.0-10.0 ft bgs at PA-P19 Elevated U (4.3 mg/kg) at 14.0-15.0 ft bgs at PA-P19 Elevated Se (1.4 mg/kg) from 18.5-20.0 ft bgs at PA-YY1 and (1.1 mg/kg) from 16.5-18.0 ft bgs at PA-YY2 	PA-VZ-11
<p>Tank Farm Dry Well #2:</p> <ul style="list-style-type: none"> EPA identified suspected Dry Well located south of the former fuel tank storage and west of the grease storage shop buildings Dry Well construction details/depth unknown 	<p>Tank Farm Dry Well #2:</p> <ul style="list-style-type: none"> No soil sampling in immediate area of suspected Dry Well Chemicals were detected below screening levels in nearby soil locations PA-J1 & PA-V2 	PA-VZ-2
<p>Assay Lab Dry Well #3:</p> <ul style="list-style-type: none"> Located proximal to the southeast corner of the former assay laboratory and warehouse Unknown quantity lab solutions conveyed by 6-in/100-ft drain line to a Dry Well 10-ft by 10-ft Dry Well 4 ft below grade, total depth unknown 	<p>Assay Lab Dry Well #3:</p> <ul style="list-style-type: none"> Soil sampling has not yet been conducted at this location. 	PA-VZ-1
<p>Solution Tanks Area Dry Well #4:</p> <ul style="list-style-type: none"> Suspected Dry Well located proximal to former cooling tower northwest of strong solution storage tanks (if not located by geophysical surveys, this location will not be characterized). 	<p>Solution Tanks Area Dry Well #4:</p> <ul style="list-style-type: none"> No soil sampling in immediate area of Dry Well, but elevated Cu, Pb, Ra-226, and Se from 0.5-1.0 ft bgs (only interval sampled) at PA-DD7 and elevated Cu, As, Cd, and Se from 0.2-2.5 ft bgs at nearby PA-DD13 	PA-VZ-7
<p>Precipitation Plant Dry Well #5:</p> <ul style="list-style-type: none"> Dry Well located at the strong solution influent location Dry Well reported to be 5 ft long by 5 ft wide and about 3.5 ft deep. Reportedly rock-filled 	<p>Precipitation Plant Dry Well #5:</p> <ul style="list-style-type: none"> Elevated Cu (420-2,600 mg/kg) from 1.0-2.0 ft bgs at PA-EE8, PA-EE17, and PA-EE18 Elevated Cd (0.39-0.54 mg/kg) from 1.0-30.5 ft bgs at PA-EE17 and PA-EE18, plus 0.5-1.5 ft bgs at PA-EE8 Elevated Pb (33-73 mg/kg) from 0.5-2.0 ft bgs at PA-EE8 and 	PA-VZ-5

Table 4-2. Proposed Vadose Zone Characterization Locations		
Source Characteristics	Soil Impacts	Location
	PA-EE17 • Elevated Ra-226 (5 and 3 pCi/g) from 1.0-2.0 and 24.5-25.5 ft bgs at PA-EE17 • Elevated Ra-228 (2.2-3.2 pCi/g) from 1.0-2.0, 4.5-5.5, and 24.5-30.5 ft bgs at PA-EE17. Although no exceedances, an increasing concentration trend to just below the background concentration observed at PA-EE18 • Elevated Se (1.2-3.7 mg/kg) from 0.5-2.0 ft bgs at PA-EE8 and PA-EE17 • Elevated Th (4.7 and 4.8 mg/kg) from 1.0-2.0 ft bgs at PA-EE1 and from 4.5-5.5 ft bgs at PA-EE18	

4.4 Proposed Groundwater Characterization Locations

Three of the vadose zone characterization boreholes described in Section 4.3 will be extended to:

- 1) provide additional groundwater elevation and chemical data underlying the Process Areas; and
- 2) install groundwater monitor wells. The three locations, shown on Figure 4-3 as PA-MW-4, -5 and -6, correspond to vadose zone characterization locations PA-VZ-13, PA-VZ-8 and PA-VZ-1, respectively, as shown on Figure 4-2. Rationale for each groundwater characterization/monitor well location is presented in Table 4-3, which have also been selected to provide a balanced spacing (north-south and east-west) of monitoring locations within the Process Areas in the context of the north-northwest flow directions depicted on Figure 3-2.

The groundwater investigation approach, which is consistent with the 2010 monitor well installation program (Brown and Caldwell, 2010c), will extend the three characterization boreholes through the saturated alluvium into the top 50 feet of underlying bedrock. Zonal groundwater samples will be collected in the saturated alluvium pursuant to the methods described in Section 5.0. If sufficient groundwater is encountered in the bedrock, a monitor well will be installed in the bedrock. If insufficient groundwater is encountered in the bedrock, no bedrock monitor well will be installed and a deep alluvial monitor well would be installed based on zonal sampling and other field data. These decisions for the initial monitor well installations at the three Process Areas locations would be made in consultation with EPA hydrogeologists.

Table 4-3. Proposed Monitor Wells Locations	
Well Location	Rationale
PA-MW-4	The proposed well is located in the Calcine Ditch used to convey waste solutions from OU3 to the Evaporation Ponds. Determine the thickness of the alluvial aquifer; provide hydrogeologic information to establish the horizontal gradient and groundwater flow direction at the north end of OU3, which appears to be hydraulically up-gradient of the Evaporation Ponds to the north; conduct zonal sampling to determine the vertical distribution of chemicals in alluvial groundwater; evaluate hydraulic gradients in the alluvium and bedrock.
PA-MW-5	The proposed well is located at the north end of the Precipitation Plant adjacent to a sump that extends approximately 30 below ground surface where elevated chemicals were detected in groundwater grab sample PA-GW18. Determine the thickness of the alluvial aquifer; provide hydrogeologic information to establish the horizontal gradient and groundwater flow direction in the vicinity of the Precipitation Plant; conduct zonal sampling to determine the vertical distribution of chemicals in alluvial groundwater; evaluate hydraulic gradients in the alluvium and bedrock.
PA-MW-6	The proposed well is located at the location of Dry Well #3. Determine the thickness of the alluvial aquifer; provide hydrogeologic information to establish the horizontal gradient and groundwater flow direction in the vicinity of the Dry Well associated with the former Assay Laboratory; conduct zonal sampling to determine the vertical distribution of chemicals in alluvial groundwater; evaluate hydraulic gradients in the alluvium and bedrock.

The saturated thickness of alluvial fan sediments in the southern portion of the Process Areas is anticipated to be limited based on: 1) alluvium in the structural graben beneath the Site thins to the south and approaches zero feet in thickness near the open pit; 2) the approximate 100-foot saturated thickness at the WW-10 location (north end of the vat leach tanks); and 3) the lack of water in borehole PA-GW1 (located approximately 800 feet south of the Process Areas).

As indicated in Section 1.3, groundwater characterization activities described in this Vadose Zone Work Plan comprise a phase in an iterative approach to groundwater investigation at the Site. Data obtained from zonal sampling of groundwater at the three monitor well locations shown on Figure 4-3, will support the design of subsequent groundwater investigations in the Process Areas (i.e., a subsequent phase of the OU-1 and/or OU-3 RI).

SECTION 5.0

FIELD SAMPLING AND ANALYSIS PLAN

5.1 Overview of Characterization Activities

This FSAP describes: 1) field activities to be conducted in the Process Areas and associated laboratory analytical programs; 2) integration and interpretation of soil geochemical and geotechnical properties; and 3) numerical modeling of the expected range of vadose zone properties within the Process Areas. Although drilling and sampling activities will be performed after the completion of sub-surface geophysical investigations of underground utilities and Dry Wells described in Section 4.2 and Appendix H, and the presentation of the results of the geophysical investigations to EPA, ARC anticipates that drilling and sampling activities at locations not associated with the Dry Wells can be initiated prior to the discussion of the geophysical results with EPA.

FSAP activities are designed to achieve the DQOs described in Section 4.1, and the investigation results will be presented in a data summary report (DSR). FSAP activities include:

- Initial geoprobe drilling/core sampling of the upper 50 feet of alluvium at the 13 vadose zone characterization borehole locations shown in Figure 4-2 and lithologic logging of the alluvial materials to pre-determined geochemical and geotechnical sample depths;
- Roto-sonic boring/core sampling of alluvial fan materials underlying the Process Areas at the same 13 locations to the capillary fringe zone immediately above the water table, and extending the depth of drilling to the alluvium-bedrock contact at the three monitor well locations (PA-MW-4, -5 and -6) shown in Figure 4-3;
- Collection of unsaturated alluvial samples from the 13 characterization boreholes for geochemical and geotechnical (hydraulic properties) analyses;
- Collection of zonal samples for chemical analyses from the three boreholes that penetrate the saturated alluvium;
- Installation of monitor wells in the three boreholes previously subjected to zonal groundwater sampling; and
- Backfilling and abandonment of the 10 boreholes not completed as monitor wells.

In addition, this FSAP presents a preliminary description of a subsequent characterization phase (vadose zone soil moisture monitoring). If performed, ARC anticipates that the design of a vadose zone monitoring program would be developed after the submittal of the DSR to, and discussions of investigation results with, EPA.

A summary of the activities for the borehole locations shown on Figure 4-2 is presented in Table 5-1. The three monitor wells to be installed, shown on Figure 4-3, are not provided depth designations in Table 5-1. Final depths for each of the three monitor wells will be determined in consultation with EPA hydrogeologists based on zonal sampling and other field data.

Table 5-1. Summary of FSAP Activities				
Borehole Location	Characterization Activities			
	Geoprobe Drilling	Sonic Core Drilling/Soil Geotechnical and Geochemical Analyses	Zonal Water Quality Sampling/Monitor Well Installation	Abandon Borehole
PA-VZ-1	X	X	X (PA-MW-6)	
PA-VZ-2	X	X		X
PA-VZ-3	X	X		X
PA-VZ-4	X	X		X
PA-VZ-5	X	X		X
PA-VZ-6	X	X		X
PA-VZ-7	X	X		X
PA-VZ-8	X	X	X (PA-MW-5)	
PA-VZ-9	X	X		X
PA-VZ-10	X	X		X
PA-VZ-11	X	X		X
PA-VZ-12	X	X		X
PA-MW-13	X	X	X (PA-MW-4)	

Quality assurance (QA) objectives for the field activities associated with the field activities described below will be implemented in accordance with the QAPP -Revision 5 (ESI and Brown and Caldwell, 2009) and as described in Section 6.0 of this Vadose Zone Work Plan.

5.2 Vadose Zone Sampling and Analysis

At the 13 borehole locations intended for vadose zone characterization, a geoprobe drilling rig will initially be used, prior to sonic core drilling, to: 1) optimize soil sample collection in the upper, most dynamic section of the soil column with respect to moisture content and hydraulic properties (see Section 5.2.1); 2) identify any lithologic horizons that may modify the planned geotechnical or geochemical sample collection intervals identified in Section 5.2.1 and 5.2.2; and 3) allow geotechnical samples to be immediately preserved to minimize soil moisture losses prior to shipment to the laboratory. The sonic core rig will be used to collect core samples for laboratory analyses of geochemical and geotechnical properties, and install three new monitor wells, at the locations identified in Table 5-1.

The boreholes listed in Table 5-1 not intended for monitor well installations, and the 13 initial geoprobe boreholes will be abandoned according to State regulations by refilling the holes with bentonite. Core samples not used for laboratory analyses will be archived on Site in core boxes to preserve their soil texture and potential future use for other laboratory analyses.

5.2.1 Lithologic Logging and Geotechnical Characterization of Soils

Upon retrieval from the geoprobe and adjacent sonic core drilling locations, unsaturated and saturated alluvial materials will be described in accordance with the American Society of Testing and Materials (ASTM) 1992, Standard D 2487-92 - Classification of Soils for Engineering Purposes Unified Soil Classification System (USCS) and SOP-12 'Field Classification and Description of Soils and Rock' (provided in the QAPP - Revision 5). Lithologic logging of geoprobe cores will be used to select depth intervals for geotechnical and geochemical samples from the upper 50 feet of the sonic cores.

The following sample collection intervals will provide a higher density in the upper 50 feet of the vadose zone where soil moisture and soil suction values are anticipated to be more variable than deeper zones based on the results from the RAC DSR (Brown and Caldwell, 2009a) and as presented in Section 3.3.2 based on Looney and Falta (2000):

- from approximately 1 to 2 feet bgs;
- from approximately 9 to 10 feet bgs;
- from approximately 19 to 20 feet bgs;
- from approximately 29 to 30 feet bgs;
- from approximately 49 to 50 feet bgs;
- from approximately 74 to 75 feet bgs;
- from approximately 99 to 100 feet bgs;
- from approximately 124 to 125 feet bgs (if unsaturated); and
- from approximately 149 to 150 feet bgs (if unsaturated).

Vadose zone modeling results presented in the RAC DSR (Brown and Caldwell, 2009a) confirmed that shallow soil zones at the Site are the most active with respect to changes in moisture content. The geoprobe drilling and lithologic logging activities to be conducted in the upper 50 feet prior to sonic core drilling will provide the opportunity to confirm or modify the sample intervals listed above, and ensure that all representative soil types are sampled for geotechnical analyses. In accordance with SOP-11 ‘Soil Sampling’ and SOP-1 ‘Environmental Sample Handling’ (QAPP - Revision 5), geotechnical samples (minimum 12-inch long intact and undisturbed core samples) will be collected and immediately sealed and packaged to minimize loss of soil moisture and any disturbance during shipping by:

- Adding plastic bubble wrap inside the open ends of the core sleeve;
- Sealing both ends with plastic caps and duct tape to retain soil moisture;
- Placing the core inside a sealed plastic bag; and
- Packaging the samples in hard-sided shipping containers (e.g., cooler).

Geotechnical analyses of the soil samples to be used to evaluate the hydraulic properties of the vadose zone alluvial materials (e.g., the potential flux of meteoric water and potential mobilization of chemicals from the unsaturated zone to the water table) will be conducted in a phased approach, as follows:

- Initial screening of samples through sieve analysis and hydrometer testing to identify soil types and the determination of gravimetric moisture content.
- Based on the results of the sieve analyses described above, 20 soil geotechnical samples (i.e., two per borehole location) will be selected to develop SWCCs in order to represent all visually- or lab-identified soil types beneath the Process Areas. SWCCs are fundamental to the characterization of unsaturated soils and required for vadose zone modeling, and will be developed using volumetric water content and pore pressure values at 5 to 7 points.
- Additional testing (e.g., Atterberg limits, saturated and unsaturated hydraulic conductivity values) in accordance with ASTM methods listed in Table 5-2.

Table 5-2. Sediment and Soil - Geotechnical Tests	
Geotechnical Test	Analytical Method
<i>Hydraulic Properties/Soil Water Characteristic Curve:</i>	
Saturated hydraulic conductivity (rigid-wall)	ASTM D2434
Initial gravimetric water content (soil moisture)	ASTM D2216
Dry bulk density	ASTM D2937/D6836
Calculated total porosity	ASTM D6836
Moisture characteristics (5-7 points)	ASTM D6836/D2325
Calculated unsaturated hydraulic conductivity	ASTM D6836
<i>Particle Size Analysis:</i>	
Standard sieves with wash and hydrometer	ASTM D422
<i>Atterberg Limits:</i>	
Liquid limit, plastic limit, plasticity index	ASTM D4318
<i>Soil Classification for Engineering Purposes</i>	
ASTM soil classification	ASTM D2487

5.2.2 Soil Geochemical Sampling and Analysis

Soil samples (1-foot intervals) will be collected from the boreholes from the following intervals, subject to modification based on lithologic logging of geoprobe and sonic cores, as described above:

- from approximately 1 to 2 feet bgs;
- from approximately 4.5 to 5.5 feet bgs;
- from approximately 9 to 10 feet bgs;
- from approximately 19 to 20 feet bgs;
- from approximately 39 to 40 feet bgs;
- from approximately 59 to 60 feet bgs;
- from approximately 79 to 80 feet bgs;
- from approximately 99 to 100 feet bgs;
- from approximately 129 to 130 feet bgs (if unsaturated); and
- from approximately 149 to 150 feet bgs (if unsaturated).

The deepest sample will be collected from a depth of approximately two to four feet above the water table (the two-foot minimum distance above the water table to limit any capillary effects). The samples will be analyzed for the parameters listed in Table 5-3, developed by ARC and EPA for background soil samples (Brown and Caldwell; 2009c) to compare Process Areas soils to native alluvial soils. Blank and duplicate soil samples will be collected in accordance with the Site-wide Quality Assurance Project Plan (QAPP - Revision 5; ESI and Brown and Caldwell, 2009), and will be labeled in the same fashion, with no obvious indication of their sample location or quality. Field logs of sampling activities will be generated and maintained in accordance with SOP-3 'Field Notes and Documentation' (QAPP - Revision 5).

The Meteoric Water Mobility Procedure (MWMP; ASTM E2242) will be conducted on two shallow vadose zone soil samples from each characterization borehole. One sample will be collected between 5 and 10 feet bgs, and a second sample will be collected between 20 and 25 feet bgs. The MWMP consists of a single-pass column leach test over a 24-hour period using Type II reagent-grade water of a quality and pH that reflects anticipated climate conditions in Nevada, including the Site. The purpose of the MWMP is to evaluate the potential for the mobilization of the metals and radiochemicals listed in Table 5-3 from shallow vadose zone soils (the same analytical suite for Site-wide groundwater monitoring). Because the MWMP requires approximately 10 pounds of sample, a minimum 1.5-foot length of four-inch core will be required for each of the 20 samples.

Table 5-3. Sediment and Soil – Geochemical Analysis			
Analyte	Analytical Method ⁽¹⁾	Unit	Reporting Limit ⁽¹⁾
Metals			
Aluminum	6010B	mg/kg	10
Antimony	6020	mg/kg	0.1
Arsenic	6020	mg/kg	0.5
Barium	6020	mg/kg	0.5
Beryllium	6020	mg/kg	0.3
Boron	6010B	mg/kg	5
Cadmium	6020	mg/kg	0.06
Calcium	6010B	mg/kg	15
Chromium	6020	mg/kg	1.0
Cobalt	6020	mg/kg	0.5
Copper	6020	mg/kg	1.0
Iron	6010B	mg/kg	5.0
Lead	6020	mg/kg	0.5
Magnesium	6010B	mg/kg	10
Manganese	6020	mg/kg	0.5
Mercury	1631	mg/kg	0.001
Molybdenum	6020	mg/kg	1.0
Nickel	6020	mg/kg	1.0
Potassium	6010B	mg/kg	50
Selenium	6020	mg/kg	0.45
Silver	6020	mg/kg	0.5
Sodium	6010B	mg/kg	50
Thallium	6020	mg/kg	0.5
Thorium (total)	6020	mg/kg	0.2
Uranium (total)	6020	mg/kg	0.1
Vanadium	6020	mg/kg	1.0
Zinc	6020	mg/kg	10
Radiochemicals			
Radium-226	EPA 903.0	pCi/g	1.0
Radium-228	EPA 904.0	pCi/g	1.0

(1) Laboratory analytical methods and reporting limits are consistent with the QAPP - Revision.5)

5.3 Groundwater Sampling and Analysis

Three of the 13 Process Areas sonic core boreholes identified in Table 5-1 will be advanced into saturated alluvium and underlying bedrock, if possible. Groundwater sampling will be conducted in the boreholes during sonic core drilling and in monitoring wells constructed at the three borehole locations once drilling is completed. As described in Section 5.3.1, depth-specific

samples will be collected from multiple borehole intervals as sonic drilling progresses through the alluvium (and a single sample from bedrock), using temporary well points at targeted intervals (Section 5.3.2) to facilitate sampling. Once samples from a specific interval have been collected, the temporary well point will be removed and sonic core drilling will continue.

Sampling procedures, field parameters to be measured, and laboratory analyses for the depth-specific samples are summarized in Section 5.3.3. The sonic core rig will also be used to install new monitor wells in the three designated characterization boreholes (Table 5-1). Section 5.3.4 describes the construction and development procedures for these new monitor wells, as well as the procedures for groundwater sampling to be conducted once well installations are completed.

5.3.1 Depth-Specific Groundwater Sampling Criteria

Consistent with procedures used during the first- and second-step hydrogeologic framework assessment (HFA) characterization activities presented in the Second Step Hydrogeologic Framework Data Summary Report (HFA DSR; Brown and Caldwell, 2008), zonal sample intervals will be determined based on lithologic logging and a visual estimation of transmissive properties of soil cores, including the occurrence of clay-rich alluvial horizons.

5.3.2 Temporary Well Installation and Development

Based on previous field experience, sonic core drilling is anticipated to encounter heaving (flowing) sands that may comprise the water-bearing intervals and/or the density/hardness of the formation that will require make-up water to wash down the six-inch casing. As in previous HFA characterization activities, make-up water will be obtained from well WW-36. Water quality in well WW-36 is monitored quarterly and analytical results from this well are presented in quarterly or annual groundwater monitoring reports (e.g., Brown and Caldwell, 2009e).

Field parameters for the make-up water will be measured daily for comparison to the field parameters measurements of ground water during low-flow purging in the event that the volumetric criterion for removal of wash down water (discussed further below) is not achieved. Experience obtained from previous groundwater investigations has resulted in the recognition

that the volumetric removal criterion has been achieved and that field parameter measurements have not yet been needed to make decisions about removal of wash down water. However, field parameters will be measured as a contingency in the event that the volumetric criterion for removal of wash down water is not achieved.

Field parameter measurements to be obtained for the make-up water include pH, specific conductivity, temperature, oxidation-reduction potential (ORP), dissolved oxygen (DO), sulfate, total alkalinity, total iron and ferrous iron. Procedures for obtaining these field parameter measurements are described below. The volume of make-up water added during drilling, and the extraction rate(s) and duration of development required to remove the added water prior to conducting low-flow purging, will be recorded on field sampling forms.

The six-inch diameter outer casing will be washed down to the bottom of the intended screened interval by pumping make-up water into the casing. Once the casing is washed down and the borehole is open to the intended depth, the temporary well (consisting of three-inch nominal diameter stainless-steel wire-wrap screen, k-packer, and low-carbon steel riser) will be installed to the intended depth. The six-inch casing will be pulled up five feet exposing the screen to the borehole. The k-packer will maintain a seal between the temporary well and the six-inch casing, which will isolate the column of water in the casing from the screened interval.

Temporary wells will initially be developed with a submersible pump. Subsequently, a bladder pump will be used to purge the temporary well and collect samples for field and/or laboratory analysis. The submersible pump (one horsepower) will be installed into the temporary well with the pump intake just above the top of the screen in an effort to prevent the pump water level from exposing the screen to the atmosphere. During development, a minimum of twice the volume of make-up water used to wash-down the 6-inch casing to the intended depth will be extracted using a submersible pump. If needed, development of the temporary wells may include periodically raising and lowering the pump as a swab, and periodically cycling the pump on and off as to induce a surge effect. Field forms will be used to document development of the depth-specific zones.

5.3.3 Depth-Specific Sample Collection Procedures

After the temporary wells have been developed using the Grundfos RediFlo3 submersible pump (or equivalent), a Grundfos RediFlo2 submersible pump (or equivalent pump capable of pumping at relatively lower flow rates) will be installed in the well to allow low-flow purging, measurement of field parameters and collection of zonal groundwater samples. The discharge rate will be reduced, as necessary, to a rate of approximately 100 to 500 milliliters per minute to help reduce turbidity during these activities. The pumping rate will be measured and recorded on field sampling forms.

Field parameters will be monitored in an air-tight flow cell equipped with a YSI 556 MPS multi-probe field meter (or equivalent). The riser/discharge tubing will be connected to the influent port on the flow-through cell. Field experience indicates that connection of in-line pre-filter(s) ahead of the flow-through cell is needed to reduce turbidity to acceptable levels. As field conditions dictate, 10-, 5-, or 1-micrometer (μm) in-line pre-filters will be used individually, or in combination, to verify that the turbidity of the water monitored in the flow through cell is less than 10 nephelometric turbidity units (NTUs) to ensure the reliability of the field stabilization data. Turbidity will be measured from the discharge point with a Hach 2100P portable turbidity meter (or equivalent). Field parameters will be monitored and recorded at time intervals sufficient to evacuate the flow-through cell volume. Meters will be calibrated in accordance with SOP-4 - 'Groundwater Monitoring Instrument Calibration' (QAPP - Revision 5).

Samples will be collected in accordance with SOP-9 - 'Groundwater Sample Collection' (QAPP - Revision 5) once volumetric and field parameter stabilization criteria are met, or after a maximum of one hour of purging. The volume-based criteria require that a minimum of two times the volume of water in the well screen and casing below the bottom of the packer be purged prior to sampling.

The parameter-based stabilization criteria include three consecutive readings that meet the following:

- Temperature is ± 3 percent relative percent difference (RPD)
- pH is ± 0.1 standard pH unit
- Conductivity is ± 3 percent RPD
- ORP is ± 20 millivolts (mV)
- DO is ± 10 percent RPD when DO exceeds 1 mg/L; ± 0.3 mg/L when DO < 1 mg/L
- Turbidity is $\pm 10\%$ RPD when turbidity exceeds 10 nephelometric turbidity unit (NTUs). Additional procedures to address high turbidity include the following:
 1. Prior to connection to the flow through cell, one screen volume will be purged from the temporary well;
 2. A water sample will be collected and turbidity measured and recorded. If the turbidity is < 30 NTU, the flow through cell will be connected and stabilization parameters will be measured and recorded. If turbidity is > 30 NTU, in-line pre-filters will be installed prior to connection to the flow through cell and stabilization parameters will be measured and recorded.
 3. Following purging of a second screen volume and achievement of well stabilization according to field parameter readings, the flow through cell and in-line pre-filters will be disconnected. A water sample will be collected and the turbidity measured and recorded.
 4. Unfiltered and filtered water samples will then be collected according to requirements for laboratory analyses.

Once the volumetric and field parameter stabilization criteria are met, or after one hour, the flow-through cell will be disconnected from the riser/discharge tubing. A $0.45\ \mu\text{m}$ in-line filter will be connected to the riser/discharge tubing to allow collection of a groundwater sample for laboratory analysis of dissolved (i.e., filtered) parameters identified in Table 5-4.

Zonal (i.e., depth-specific) samples will be collected in lab-supplied bottles, preserved, cooled, documented, and sent to the laboratory for analyses of the parameters listed in Table 5-5 for monitor well sampling. Aliquots of the $0.45\text{-}\mu\text{m}$ filtered water will also be collected for field measurement of sulfate utilizing a HACH DR/2400 portable lab spectrophotometer, total alkalinity using a HACH alkalinity titration kit, and total iron and ferrous iron using a CHEMetrics, Inc. colorimetric field analysis kit. Field measurements of sulfate and total alkalinity will be made in accordance with HACH Methods 8051 and 8203, respectively. Total and ferrous iron will be made in accordance with CHEMetrics, Inc. Method K-6010. The results of the field kit field measurements will be recorded on field sampling forms.

Table 5-4. Zonal Sampling Field and Laboratory Parameters				
Measurement / Parameter	Field / Laboratory	Method	Measurement / Detection Limit	Units
pH	Field Meter	EPA 150.1, Meter	0.1	Standard Unit
Conductivity	Field Meter	EPA 150.1, Meter	1	uS/cm
Temperature	Field Meter	Standard Methods 212, Thermometer	0.1	° Centigrade
Dissolved Oxygen (DO)	Field Meter	EPA 360.1, Probe	0.1	mg/L
Oxidation-Reduction Potential (ORP)	Field Meter	SM 2580 B	1	mV
Iron (Total)	CHEMetrics, Inc Water Analysis Kit	CHEMetrics, Inc Method K-6010, Colorimetric	0.02 – 3.0	mg/L
Iron (Ferrous)	CHEMetrics, Inc Water Analysis Kit	CHEMetrics, Inc Method K-6010, Colorimetric	0.02 – 3.0	mg/L
Sulfate	HACH Field Water Analysis Kit	HACH Method 8051 (SulfaVer 4 Method)	2	mg/L
Alkalinity as CaCO ₃	Laboratory	HACH Method 8203 (Phenolphthalein Method)	10	mg/L
Uranium (total and dissolved)	Laboratory	EPA 200.8, ICP-MS	0.01	mg/L
Uranium-234, 235, 238 ⁽¹⁾	Laboratory	EPA 907.0	1.0	pCi/L
Total Organic Carbon (TOC)	Laboratory	EPA 415.1 (combustion/oxidation)	2.0	mg/L

Accuracy of the sulfate and alkalinity field analyses will be achieved by using the Standard Solution Methods, as recommended by the manufacturer. Standard solutions will be created daily for total iron and sulfate, and will be used to adjust the spectrophotometer to the standard solution prior to each analysis. Accuracy of the field measurements for total and ferrous iron will be achieved using the colorimetric reference standards provided by CHEMetrics, Inc.

After filtered samples are collected, the 0.45 µm in-line filter and any other in-line pre-filters will be removed and a groundwater sample will be collected for laboratory analysis of total (i.e., unfiltered) parameters identified in Table 5-4. A final turbidity measurement of the unfiltered ground water will be obtained using the HACH field kit and recorded on a field sampling form. After the depth-specific zonal sample is collected, the pump will be removed and the temporary well will be pulled from the borehole.

The six-inch casing will be washed down to the bottom of the last core run and drilling with the core barrel will resume. This method of coring, washing down casing, installing the temporary well, purging, collecting a groundwater sample, washing down casing, and coring again will be generally repeated in 20-foot intervals between the upper water bearing zone and the target depth of each borehole.

5.3.4 Well Construction, Development and Sampling

Procedures for drilling and depth-specific sampling will be consistent with the EPA-approved procedures used during the 2010 monitor well installation program (Brown and Caldwell, 2010c). A groundwater monitor well with a nominal 20-foot screen interval will be constructed in the bedrock or deeper portion of the alluvial aquifer at each of the three Process Areas locations. As described above: 1) the well screen will be positioned in consultation with EPA hydrogeologists based on field data; and 2) subsequent phases of groundwater investigations may include additional monitor wells at these locations, or other locations within the Process Areas, pending further discussion with EPA.

Once constructed, monitor wells will be developed and surveyed. After development, groundwater samples will be collected from the wells for laboratory analysis, as described below. Monitor well construction and development activities will be performed in accordance with the QAPP - Revision 5 (ESI and Brown and Caldwell, 2009).

Well Construction Methods

The three monitor wells will be constructed to allow for the collection of groundwater elevation measurements and groundwater quality samples. Monitor wells will be constructed with a nominal 15-foot long, 6-inch diameter steel surface casing and 2-inch diameter schedule 40 polyvinyl chloride (PVC) tubing as the blank (i.e., not screened) portion of the well. Approximately three feet of the steel surface casing will stick up above the ground surface to protect the plastic tubing of the monitor well.

A 20-foot, 0.020-inch slotted screen constructed of schedule 40 PVC will be installed at the design interval. A 2-inch flush-threaded PVC end cap will be placed at the bottom of the screened interval. Where necessary, the borehole beneath the screen and bottom cap will be filled with fully hydrated bentonite grout (nominally 0.375-inch pellets), installed via tremmie pipe, to three feet below the bottom of the well.

A filter pack consisting of 10/20 silica sand, installed via tremmie pipe, will be placed in the borehole annulus throughout the screen interval and will extend approximately three feet above the top of the screen interval (i.e., 23 feet of filter pack placed in the annulus assuming a 20-foot well screen). A minimum 1-foot thick finer filter-pack layer will be placed on top of the coarser filter pack, and a bentonite seal will be installed between the top of the finer sand and the cement grout to limit cement grout intrusion. The cement seal will be placed in the annular space from the top of the filter pack to ground surface.

A locking 6-inch diameter well monument will be installed with an approximate 3-foot stick-up above ground surface. A nominal 6-inch thick, 2-foot by 2-foot concrete slab will be placed around the surface casing. The well monument will contain the monitor well name with shallow, intermediate or deep designations (e.g., PA-MW-4S and PA-MW-4D). A permanent water level measurement point will be marked on the PVC well casing inside the monument.

A Nevada-registered surveyor will survey the horizontal and vertical locations of each new monitor well, including the ground surface and top-of-casing elevations. The permanently marked reference measurement point (i.e., at the top of the PVC well casing) for taking depth-to-water measurements will be surveyed within +/-0.1 foot in relation to National Geodetic Vertical Datum (NGVD) 29, and within +/- 0.05 foot relative to Nevada State Plane West Zone coordinates (North American Datum [NAD] 27).

Well Development

After the bentonite grout and cement surface seal has cured, each monitor well will be developed to remove fine-grained material from the well and to improve hydraulic communication with the

aquifer. Development procedures include surging the well and periodically pumping or bailing fine grained material until the turbidity of the discharge water is less than or equal to 10 NTUs or has stabilized (i.e., varies less than +/- 10% over three successive casing volumes).

Well Sampling

Parameters for groundwater samples include: 1) field measurements of pH, conductivity, temperature, DO and ORP; and 2) laboratory analysis of the constituents listed in Table 5-5. Prior to sampling, the groundwater quality monitoring probes/meters including pH, conductivity, temperature, DO and ORP will be calibrated daily in accordance with manufacturer's instructions. At a minimum, two-point calibrations will be conducted for pH and conductivity. The dissolved oxygen probe will be checked against a zero-dissolved oxygen solution. The dissolved oxygen calibration will be corrected for local barometric pressure and elevation.

Groundwater samples will be collected from the newly installed monitor wells using dedicated pumps and low-flow (minimal drawdown) sampling procedures that are consistent with EPA guidance (EPA, 1996) and in accordance with the revised Site-Wide Groundwater Monitoring Plan (Brown and Caldwell, 2009d). Decontamination of any non-dedicated equipment used to purge and sample the monitor wells will be performed in accordance with the QAPP - Revision 5. After initial sampling, these wells will be included in the quarterly monitoring program.

Table 5-5. Analyte List for Monitor Well Sampling				
Parameter or Analyte	Total/ Dissolved	Method ⁽¹⁾	Reporting Limit ⁽¹⁾	Units
Physical Parameters and Major Anions/Cations				
Alkalinity (Total as CaCO ₃)	Total	SM 2320B	2.0	mg/L (as CaCO ₃)
Bicarbonate (HCO ₃ as CaCO ₃)	Total	SM 2320B	2.0	mg/L (as CaCO ₃)
Carbonate	Total	SM 2320B	2.0	mg/L (as CaCO ₃)
Chloride	Total	EPA 300.0	0.5	mg/L
Fluoride	Total	EPA 300.0	0.5	mg/L
Nitrate	Total	EPA 300.0	0.1	mg/L as N
Nitrite	Total	EPA 300.0	0.1	mg/L as N
Sulfate	Total	EPA 300.0	0.5	mg/L
pH	Total	SM 4500B	0.1	pH Units
Total Dissolved Solids (TDS)	Total	SM 2540C	10	mg/L
Total Organic Carbon (TOC)	Total	SM 5310B	1.0	mg/L

Table 5-5. Analyte List for Monitor Well Sampling				
Parameter or Analyte	Total/ Dissolved	Method ⁽¹⁾	Reporting Limit ⁽¹⁾	Units
Metals				
Aluminum	Dissolved	EPA 200.7	0.05	mg/L
Antimony	Dissolved	EPA 200.8	0.002	mg/L
Arsenic	Dissolved	EPA 200.8	0.001	mg/L
Barium	Dissolved	EPA 200.8	0.001	mg/L
Beryllium	Dissolved	EPA 200.8	0.0005	mg/L
Boron	Dissolved	EPA 200.7	0.05	mg/L
Cadmium	Dissolved	EPA 200.8	0.001	mg/L
Calcium	Dissolved	EPA 200.7	0.1	mg/L
Chromium	Dissolved	EPA 200.8	0.002	mg/L
Cobalt	Dissolved	EPA 200.8	0.001	mg/L
Copper	Dissolved	EPA 200.8	0.001	mg/L
Iron	Dissolved	EPA 200.7	0.04	mg/L
Lead	Dissolved	EPA 200.8	0.001	mg/L
Lithium	Dissolved	EPA 200.8	0.002	mg/L
Magnesium	Dissolved	EPA 200.7	0.02	mg/L
Manganese	Dissolved	EPA 200.8	0.001	mg/L
Mercury	Dissolved	EPA 245.1	0.0002	mg/L
Molybdenum	Dissolved	EPA 200.8	0.002	mg/L
Nickel	Dissolved	EPA 200.8	0.002	mg/L
Phosphorus	Dissolved	EPA 200.7	0.04	mg/L
Potassium	Dissolved	EPA 200.7	0.5	mg/L
Selenium	Dissolved	EPA 200.8	0.002	mg/L
Silicon	Dissolved	EPA 200.7	0.05	mg/L
Silver	Dissolved	EPA 200.8	0.001	mg/L
Sodium	Dissolved	EPA 200.7	0.5	mg/L
Strontium	Dissolved	EPA 200.7	0.02	mg/L
Thallium	Dissolved	EPA 200.8	0.001	mg/L
Tin	Dissolved	EPA 200.7	0.1	mg/L
Titanium	Dissolved	EPA 200.7	0.005	mg/L
Uranium, Total	Dissolved	EPA 200.8	0.001	mg/L
Vanadium	Dissolved	EPA 200.8	0.002	mg/L
Zinc	Dissolved	EPA 200.8	0.01	mg/L
Radiochemicals				
Gross Alpha	Dissolved	EPA 900.0	1.0	pCi/L
Gross Beta	Dissolved	EPA 900.0	1.0	pCi/L
Radium-226	Dissolved	EPA 903.0	1.0	pCi/L
Radium-228	Dissolved	EPA 904.0	1.0	pCi/L
Thorium-228	Dissolved	HASL 300	1.0	pCi/L
Thorium-230	Dissolved	HASL 300	1.0	pCi/L

(1) EPA laboratory analytical methods and method detection limits are consistent with the QAPP - Revision 5.

Sample Handling, Labeling, Transport and Documentation

Preparation of groundwater samples in the field for transport to the laboratory (e.g., handling, labeling, packaging, documentation, chain-of-custody) will be conducted in accordance with the QAPP - Revision 5 (ESI and Brown and Caldwell, 2009). Sample handling and related procedures are described further in Section 6.3.

5.4 Vadose Zone Modeling

Vadose zone modeling using the saturated/unsaturated flow code SVFLUXTM will be conducted to evaluate the potential flux of meteoric water within the soil profiles underlying the Process Areas. SVFLUXTM is a SoilVision product that represents the state-of-the-art for such models. Pending the results of soil property characterization, ARC anticipates that up to three one-dimensional column models will be constructed to characterize the vadose zone, and that each model will have an upper climate boundary and a lower boundary representing the water table.

The models will evaluate vadose zone infiltration flux and seasonal moisture movement into and out of the model domain. Because the stratigraphic sequence and soil properties are expected to differ between borehole locations, the column models will be constructed as generalized, representative composites that integrate the material types encountered in the boreholes. This was the approach used to simulate conditions beneath the Anaconda evaporation ponds (Brown and Caldwell, 2009a).

5.4.1 Material Properties

Unsaturated hydraulic characteristics of the soils included in the column models will be specified based on geotechnical laboratory test results including SWCCs, measured saturated hydraulic conductivity (Ksat), grain size analyses, dry and wet bulk density, gravimetric and volumetric water content, and calculated porosity. Laboratory results will be used to model the relationship between unsaturated hydraulic conductivity and moisture content for each of the soil types, which will largely be dependent on the SWCCs. The relationship between unsaturated hydraulic

conductivity and moisture content will be modeled with the SoilVision software, likely employing the method of Fredlund, et al. (1994) or Campbell (1973), which were both used in the vadose zone modeling presented in the RAC DSR (Brown and Caldwell, 2009a).

5.4.2 Atmospheric Input Data

Atmospheric inputs to the vadose zone models consist of precipitation and evaporation. Daily precipitation data will be obtained from the Western Regional Climate Center web site (<http://www.wrcc.dri.edu/>), for the Yerington, Nevada Coop site #269229. The 15-year climate record, used for the RAC DSR simulations, is summarized in Table 5-6 and includes: 1) the range of average annual precipitation rates expected at the Site, represented by a greater number of below average (dry) years (late 1970s to early 1980s) followed by a shorter number of above average (wet) years (early to mid-1980s); and 2) a high precipitation year (8.99 inches in simulation year 11) that is 75 percent greater than the 5.12-inch annual average for the 95-year period of record (1914 through 2008) at Site # 269229.

Table 5-6. Annual Precipitation Values for Simulation Period	
Simulation Year (Water Year)	Model Precipitation Input (inches/meters)
1 (1972/73)	5.50/(0.1397)
2 (1973/74)	3.13/(0.0795)
3 (1974/75)	5.95/(0.1511)
4 (1975/76)	4.02/(0.1021)
5 (1976/77)	4.69/(0.1191)
6 (1977/78)	4.58/(0.1163)
7 (1978/79)	3.51/(0.0892)
8 (1979/80)	4.61/(0.1171)
9 (1980/81)	3.88/(0.0986)
10 (1981/82)	2.78/(0.0706)
11 (1982/83)	8.99/(0.2283)
12 (1983/84)	7.68/(0.1951)
13 (1984/85)	7.26/(0.1844)
14 (1985/86)	7.96/(0.2022)
15 (1986/87)	3.96/(0.1006)

Because instantaneous storm events can be problematic in numerical model simulations, storm events are scaled using either a parabolic or tetrahedral shape to smooth this input parameter. The SVFlux software performs calculations such that the total volume of water applied to the soil on any particular day is consistent with input data regardless of the storm shape selected. For the planned simulations, the modeled temporal distribution of precipitation intensity will be globally set to a parabolic distribution over an eight-hour period.

Evaporation data for the model simulations, also used in the RAC DSR, are based on pan evaporation data for the Lahontan, Nevada Coop site #264349, located approximately 30 miles north of the Site (evaporation data are not available for the Yerington, Nevada Coop site). Pan evaporation data from the Site will not be used because these data represent a period of less than 10 years (the Lahontan site includes approximately 60 years of data). The Lahontan site was selected based on its proximity to the Site, its climatic similarity to the Site, and the availability of the data as monthly average values for the period of record. Table 5-7 presents these evaporation data as daily average evaporation rate by month. Evaporation data used in the simulations will be adjusted by a pan coefficient of 0.7 to correct for factors (e.g., storage and transfer of heat to the water from the sides of the evaporation pan), which may increase the evaporation rate in an open pan with respect to the potential evaporation from a crop or bare soil (coefficients vary from 0.35 to 0.85 for agricultural situations; UNFAO, 1998). The pan coefficient effect lowers the potential evaporative flux indicated by the pan evaporation data.

Table 5-7. Daily Average Pan Evaporation Rates	
Month	Daily Average Evaporation (centimeters)
January	0.00
February	0.00
March	0.00
April	0.61
May	0.79
June	0.98
July	1.13
August	1.00
September	0.66
October	0.37
November	0.18
December	0.00

5.4.3 Boundary Conditions

Boundary conditions will be assigned to the upper and lower surfaces of the one-dimensional models (lateral boundaries will be designated as no-flow boundaries). The upper boundary will simulate atmospheric conditions, and the lower boundary will be represented by a gradient boundary because of the relatively large depth to groundwater beneath the Process Areas (e.g., typically at depths of 90 to 150 feet bgs). This lower boundary condition will eliminate the unrealistic potential of the model to wick soil moisture sourced from the underlying alluvial aquifer. As described in the RAC DSR, a gradient boundary condition of 0.6 was simulated for the Finger Evaporation Ponds with a depth to groundwater of at least 65 feet bgs.

5.4.4 Initial Conditions

Initial moisture conditions for the models will be developed using SVFlux™ to establish a linear distribution of pressure head between the water table and the upper model boundary. The models will be run until they are at or near equilibrium (i.e., quasi steady-state condition) with boundary conditions prior to assessing model results. Equilibrium will be indicated by a cessation of any long-term drying or wetting trends exhibited by the models. Following this initial equilibration period, the saturation within the model is characterized by short-term, seasonal variations that are superimposed on a quasi steady-state saturation condition.

5.4.5 Interpretation of Model Results

Comparisons of observed versus simulated saturation percentages within the column models indicate the appropriateness of the numerical models for predictive simulations (i.e., approximating the observed moisture conditions with the models). A tool for monitoring saturation at various locations within the model domain, called point saturation monitors (saturation points), is also provided by SVFlux™. The saturation points provide a history of the degree of saturation at designated locations within the column models for the simulation period, and are used to compare observed with simulated saturation percentage values.

Flux lines will be designated in each model to evaluate the movement of soil water at various depths (flux lines are a tool included in SVFlux™ that allows the user to monitor and record the

flux of soil water anywhere in the column model). Flux lines were placed at shallow, intermediate and deep levels of the RAC DSR vadose zone models. The deepest flux line was used to estimate deep soil water movement (i.e., whether soil moisture moved up or down, the flux rate, and the total cumulative flux volume).

5.5 Vadose Zone Monitoring

Following the vadose zone modeling activities and the submittal of the DSR for this Vadose Zone Work Plan, ARC plans to discuss vadose monitoring with EPA as the next step in the vadose zone characterization of the Process Areas. Soil moisture data collected for the vadose zone characterization and modeling activities described in Sections 5.2 and 5.4 provide a temporally singular basis for the characterization of the soils beneath the Process Areas. The objective of the proposed monitoring activities will be to provide real-time vadose zone moisture data at multiple depths below the ground surface, which will be used to validate the three column models described above. The duration of the monitoring period, and associated DQOs, would be discussed with EPA in a technical meeting.

Vadose zone moisture monitoring could be accomplished through the installation of time domain reflectometry (TDR) probes installed in either angle or vertical boreholes at selected depths. The TDR probes will be connected to data loggers that will record data from the TDR probes. TDR functions by injecting a very fast rise time step voltage increase into a waveguide (usually a coaxial cable) that carries the pulse to a probe that is placed in the soil. The velocity of the pulse in the probe is measured and related to soil water content.

TDR became known as a useful method for soil water content measurement in the 1980s (Evet, 2003). Because of the highly non-linear relationship between soil moisture and hydraulic conductivity in unsaturated soils, small temporal variations in water content cause large temporal variations in hydraulic conductivity. A reasonable estimation of the temporal variations in water content must be obtained for a reasonable estimation of the temporal variations in hydraulic conductivity (Rimon, et al., 2007).

SECTION 6.0

QUALITY ASSURANCE PLAN

Characterization activities proposed in this Vadose Zone Work Plan will be conducted pursuant to the QAPP (Revision 5) including: standard operating procedures, equipment calibration and maintenance, field and laboratory QC samples, data validation, corrective action, and data completeness. The goal of the QA program is to produce data that are consistent, have little bias, high precision and achieve the DQOs described in Section 4.0. QA procedures will be implemented on field data collection and sampling as well as laboratory analytical methods. A review of data results will be completed by the project QA oversight contractor, ESI, in order to determine whether the project data goals have been met and if any data must be qualified or rejected due to data quality issues. The QA/QC issues for this Vadose Zone Work Plan include:

- Sample identification, handling, and transport;
- Equipment decontamination;
- The use of quality control samples such as blanks and duplicates;
- Field documentation; and
- Data review.

Duplicate samples will be collected at a frequency of one in ten samples for each analysis by filling the bottles for each analysis at the same time the original sample is collected. Each sample from a duplicate set will have a unique sample number labeled in accordance with the identification protocol, and the duplicates will be sent to the lab with no special labeling of the duplicate (i.e., ‘blind’ sample).

A field sample will be designated as the ‘Lab QC Sample’ at a frequency of 1 per 20 samples (including blanks and duplicates) for all parameters. The lab QC sample is the sample the laboratory would use for its internal quality control analyses. The lab QC sample for water analyses will be a double volume sample that is representative of other contaminated samples. The sample containers and paperwork would be clearly labeled ‘Lab QC Sample’.

A field trip blank sample will be collected by pouring the blank water directly into the sample bottles at one of the sample locations. De-ionized water would be used for collecting blank water samples. Field trip blanks would be labeled in the same manner as other samples and would be sent “blind” to the lab, with no special indication of the nature of the sample.

6.1 Sample Identification

Each sample will be placed in a clean, unused sample container provided by the laboratories and will be labeled with the sample identification number. The labels will be filled out with a permanent marker and will include the following information:

- Sample identification
- Date and time of sample collection
- Sampler’s initials
- Analyses requested
- Preservation method (if required)
- Project name

Each sample will be tracked according to its unique sample field identification number assigned when the sample is collected and recorded clearly in the field notebook. The field identification number will include:

- Specific area and location type (e.g., PA = Process Areas, VZ = vadose zone, MW = monitor well)
- Location number (e.g., 4) and sample depth (e.g., @ [top] – [bottom])

For example, a sample collected from the vadose zone location 4 at a depth of 9-10 feet bgs would be labeled PA-VZ-4 @ 9-10. All final sample locations and designations will be presented in the DSR.

6.2 Equipment Decontamination

As needed, with the exception of disposable equipment, all sample collection equipment will be decontaminated between each sample. SOP-05 'Equipment Decontamination' (QAPP - Revision 5) provides detailed procedures on project implementation of equipment decontamination. In general, sampling equipment will be hand-washed with a solution of tap water and Alconox detergent, rinsed with distilled or tap water, rinsed with a weak nitric acid solution, and a final rinse in clean distilled water.

6.3 Handling and Preservation

As described above, all collected samples will be preserved according to the requirements of the analytical method and the QAPP - Revision 5 (ESI and Brown and Caldwell, 2009), and will be analyzed within the designated hold time, which varies for different analytes, as presented in Table 6-1. Preparation of groundwater samples in the field for transport to the laboratory (e.g., handling, labeling, packaging, documentation, chain-of-custody) will also be performed in accordance with the QAPP - Revision 5.

Table 6-1 provides the required sample volume, container, preservative and holding time required for each analytical method. Variations in sample volume may be requested by the project laboratories. Immediately following collection, samples will be placed into an insulated cooler and chilled with ice if temperature preservation is required. Samples will then be transported to the analytical laboratories.

After field parameters have stabilized, a groundwater sample will be collected from the submersible pump discharge line installed in the well. The sample will be decanted into an appropriate sample container depending on the required analysis. Filtered and unfiltered samples will be collected in 500-milliliter (mL) bottles. Samples for dissolved metals analysis will be filtered through a 0.45- μ m filter.

Table 6-1. Sample Containers, Preservation, and Holding Times				
Parameter	Suggested Volume	Container	Preservative	Holding Time from Collection
Soil/Sediment				
Metals	50 g	WM	≤6°C	180 days; 28 days for mercury
Radionuclides	500 g	Plastic bag	None	180 days
MWMP	5 kg	Plastic bag	None	180 days
SWCC/Geotechnical	~1 kg	Plastic core sleeve	None	NA
Groundwater				
Metals (dissolved)	500 mL	P	Field Filtered; HNO ₃ to pH<2	180 days; 28 days for mercury
Radiochemicals	4 L	P	HNO ₃ to pH<2	180 days
Alkalinity	200 mL	P or G	≤6°C	14 days
Chloride, Fluoride, Total Nitrate/Nitrite, Sulfate	200 mL	P or G	≤6°C	28 days
Nitrate and Nitrite	200 mL	P or G	≤6°C	2 days (48 hours)
pH	200 mL	P or G	≤6°C	1 day (24 hours)
TOC	200 mL	G/T	≤6°C, H ₃ PO ₄ to pH<2	28 days

Notes:

WM - Wide-mouth glass container

P - Plastic container

G - Glass container

G/T - Glass container with Teflon lined cap/septum

Immediately after collecting the groundwater sample, nitric acid will be added to each sample container until the field pH measurement of the sample is less than 2 standard units. For all non-metal analytes except total organic carbon (TOC), samples will be collected in 500-mL bottles with no acid preservative. Unfiltered samples for TOC will be collected in 500-mL bottles and acidified to pH<2 with phosphoric acid. Immediately following collection, samples will be placed into an insulated cooler chilled with ice to temperature of about six degrees centigrade. The samples will then be transported to the laboratory via overnight mail or personal delivery. Sample containers, preservation methods, and filtering methods are summarized below.

Sample labels will be completed with a permanent marker and attached to each sample container prior to ground water collection (each sample label corresponds to the collection sequence number marked on the bottle prior to sample collection). The labels will, at a minimum, include the following information:

- Sample identification and type;
- Sample date and time;
- Sample preparation and preservative;
- Analyses to be performed; and
- Person who collected the sample.

Each sample will be tracked according to a unique sample field identification number assigned when the sample is collected. This field identification number consists of three parts:

- Sampling event sequence number
- Sampling location
- Collection sequence number

Blanks and duplicate samples for quality assurance (QA), in accordance with the QAPP (Revision 5) will be labeled in the same fashion, with no obvious indication of their sample location or quality. The following sample preservation methods will be followed for collected groundwater samples:

- If the sample is to be analyzed for dissolved metals, filter sample through a 0.45- μ m filter using an in-line filter immediately after sample collection. After filtering, add nitric acid to the sample until the pH is less than 2.
- If the sample is to be analyzed for total metals, do not filter. Add nitric acid to the collected sample until the pH is less than 2.
- If the sample is to be analyzed for TOC, do not filter. Add phosphoric acid to the collected sample until the pH is less than 2.
- Check the pH by pouring a small amount of sample into the bottle cap and checking the pH with pH paper. Discard the liquid in the cap after checking the pH.
- Replace the cap, place the sample container in a sealed zip-loc plastic bag, and cool the sample to 6°C by immediately placing it in an insulated chest with containerized ice.
- Indicate on the sample label what the requested analysis is (e.g., dissolved or total).
- Observe the maximum holding times and storage conditions for all collected water samples.

Field equipment blanks will be collected to verify effective decontamination procedures by rinsing the sampling equipment including the sampling pump with deionized water and submitting the collected sample for laboratory analysis. Equipment rinse blanks will be collected at a frequency of 1 per 20 primary samples collected. Chain-of-custody protocols will be followed, and each chain-of-custody form will contain the following information:

- Project name
- Sampler's name and signature
- Sample identification
- Date and time of sample collection
- Sample matrix
- Number and volume of sample containers
- Analyses requested
- Filtration completed or required
- Method of shipment

The following sample packaging and shipment procedures will be followed for collected water samples to ensure that samples are intact when they arrive at the designated laboratory:

1. Place a custody seal over each container, and place each container in a zip-loc plastic bag and seal the plastic bag shut.
2. Place the sealed containers in the insulated ice chest.
3. If required, fill empty spaces in the ice chest with ice, styrofoam popcorn or bubble-pack wrap to minimize movement of the samples during shipment. Contained ice would be double bagged in zip-loc plastic bags to avoid water leakage.
4. Enclose the chain of custody form in a zip-loc plastic bag. If shipping the ice chest, tape the plastic bag to the inside of the ice chest lid. If self-transporting the ice chest, tape the plastic bag to the outside of the ice chest lid. Keep a copy of all paperwork.
5. Seal the ice chest shut with strapping tape and place two custody seals on the front of the cooler so that the custody seals extend from the lid to the main body of the ice chest.
6. If shipping the ice chest, label it with 'Fragile' and 'This End Up' labels. Include a label on each cooler with the laboratory address and the return address.
7. Transport ice chests to the appropriate laboratory within 24 hours by hand-delivery or via express overnight delivery.

Documentation

A summary of all field activities will be recorded in a notebook with bound pages, and entries will contain accurate and inclusive documentation of project activities in objective and factual language. Entries will be made using permanent waterproof ink, and erasures are not permitted. Errors will be single-lined out, should not be obscured, and initialed and dated. The person making the entries will sign at the beginning and the end of the day, and a new page will be used for each day. The following entries would be made to the bound logbook and/or filed log sheets:

- General descriptions of weather conditions
- Location of each sampling point
- Date and time of sample collection (field log sheets)
- The type of blank collected and the method of collection
- Field measurements made, including the date and time, and calibration information
- Reference to photographs taken
- Date and time of equipment decontamination
- Field observations and descriptions of problems encountered
- Duplicate sample location

6.4 Quality Control Samples

The QA objectives for the sample-handling portion of the field activities are to verify that sample collection, packaging and shipping are not introducing variables into the sampling chain that could provide any basis to question the validity of the analytical results. In order to fulfill these QA objectives, QC samples will be prepared and submitted. If the analysis of the QC sample indicates that variables were introduced into the sampling chain, then the samples shipped with the questionable QC sample will be evaluated for the possibility of cross-contamination in the field or breach of laboratory QC. All blanks and duplicate samples will be labeled in the same manner as regular samples, with no indication that they are QC samples, and will be submitted for the same analytical suite as the related normal samples.

Field Duplicates – Field duplicates are used to check for sampling and analytical error, reproducibility, and homogeneity. Duplicate samples will be collected at a frequency of one per every 10 investigation samples (10 percent) and each sample from a duplicate set will have a unique sample identification. Duplicate sediment and soil samples will be collected by gathering twice the sample volume in a plastic ziplock bag or stainless steel bowl, blending the entire volume to homogenize the soil, and splitting the blended soil into separate containers for the original and the duplicate samples. Splitting of the sample will be completed by alternately spooning portions of the blended sample into the original and duplicate sample containers. Duplicate water samples will be collected by filling a separate set of sample containers at the same time and from the same sample location as the original.

Equipment Rinsate Blanks – Analyses of equipment rinsate blanks are used to assess the efficiency of field equipment decontamination procedures in preventing cross-contamination between samples. Equipment rinsate blanks will be collected at a frequency of one per 20 samples (5 percent), and at least once each day samples are collected, by pouring laboratory grade de-ionized water over the decontaminated reusable sampling equipment and collecting the water in a clean container.

Field Blanks – Field blanks are used to assess possible contamination of samples during sample collection due to airborne contaminants. Field blanks are collected by pouring laboratory grade de-ionized water into a sample container under the same field conditions as the original sample was collected. They will be collected at a frequency of one per 20 samples (5%).

Matrix Spike/Matrix Spike Duplicate (MS/MSD) Samples – MS/MSD samples are investigative samples to which known amounts of analytes are added in the lab before analysis. The recoveries for spiked compounds can be used to assess how accurate the analytical method is for the site-specific sample matrix. One MS/MSD sample should be analyzed for every 20 samples (5 percent) submitted to the lab.

6.5 Field Documentation

Summary of field measurements and sampling activities will be recorded in a bound field logbook or log sheets, and entries must contain accurate and inclusive documentation of project activities as described in SOP-03 ‘Field Notes and Documentation’. Entries will be made using permanent waterproof ink, and erasures are not permitted. Errors will be single-lined out, should not be obscured, then initialed and dated. The person making the entries will sign at the end of each day’s entry, and a new page will be started for each day of sampling. The following entries will be made:

- General descriptions of weather conditions
- Location of each sampling point
- Data and time of sample collection
- The type of QC sample collected and the method of collection
- Field measurements made, including the date and time of measurements
- Calibration and/or checks of field instruments
- Reference to global positioning system (GPS) and photographs
- Date and time of equipment decontamination
- Field observations and descriptions of problems encountered

Soil borings will be logged at the time of sample collection using the Unified Soil Classification System Standard D 2487-92, developed by ASTM. Classification of soil types will include grain size, sorting, and plasticity among others and will be recorded on a separate log sheet. Observations of soil horizons or changes in soil characteristics as observed in the excavation will be recorded in accordance with the QAPP - Revision 5 (ESI and Brown and Caldwell, 2009).

6.6 QA/QC Review

Final geochemical data reported by the laboratories will undergo review by a QA oversight contractor under the direction of ARC. Analytical data verification/validation procedures are required by the QAPP - Revision 5 to qualify data results that may be inaccurate due to data

quality limitations (e.g., contaminated blanks, exceedance of sample holding times, or lab control standards [LCS] outside acceptable limits). Data verification will be completed on eighty percent (80%) of all project samples and includes review of the following measures:

- Sample holding times,
- Accuracy (by evaluating MS/MSD and LCS recovery),
- Precision (by evaluating field and lab duplicate results),
- Blank contamination,
- Surrogate compound recoveries,
- Chain-of-custody, and
- Case narrative.

Level IV data validation will be completed on the remaining 20 percent (20 percent) of samples that, in addition to the verification review listed above, will include a review of all raw laboratory data and calculations such as:

- Initial and continuing instrument calibration logs;
- Interference check samples;
- Reporting limits and sample recovery summaries; and
- Sample preparation and analytical run logs.

Analytical results will be evaluated during the verification/validation review of data received from the laboratories, and will also include a completeness check to ensure that all data has been properly loaded into the database used for report generation. Data that fail to meet the QA objectives for the characterization of background materials associated with the Yerington Mine Site will be qualified as to usability and potential low or high bias. The review of analytical data will follow the basic guidance provided in the National Functional Guidelines for Inorganic Data Review (EPA, 2004), unless specified otherwise.

SECTION 7.0

DATA MANAGEMENT AND REPORTING

Data generated during implementation of this Work Plan will be managed in accordance with the *Data Management Plan for the Yerington Mine Site* (Brown and Caldwell, 2007a). The DMP, which supplements the requirements and specifications stated in the FSAP described in Section 5.0 and the QAPP - Revision 5, documents the guidelines for sample tracking, storage, access, delivery, and reporting of historical and new chemical analytical, geologic, biologic and spatial data generated by investigation operations. Key data management objectives include:

- Provide data users with tools that allow simple and rapid access to stored data of various types, and methods of data entry and data loading with known accuracy and efficiency;
- Apply well-documented data validation modifications to the electronic database;
- Manage sample data using a unique sample identification number;
- Establish a sample inventory of new data, provide methods of sample inventory reconciliation, and store sample-specific attributes (i.e., location identifier, sample type, sample media, depth, date, and target study area);
- Provide reporting and delivery formats from a single database source to support data analysis, site characterization, risk assessment, modeling, and spatial analysis;
- Provide the ability to electronically compare results to project-specific reference or screening criteria; and
- Identify needs for incorporating historical data and establish a database of this information when possible; otherwise, establish a data inventory plan that identifies and catalogues historical data not suited for database entry.

SECTION 8.0

HEALTH AND SAFETY

All field activities will be conducted in accordance with the *Site Health and Safety Plan* (HASP; Brown and Caldwell, 2009f). The HASP identifies, evaluates and prescribes control measures for health and safety hazards, including radiological hazards, and describes emergency response procedures for the Site. HASP implementation and compliance is the responsibility of Brown and Caldwell, with ARC taking an oversight and compliance assurance role. Copies of the HASP are located at the Site and are available to all Site workers. The HASP includes site specific requirements and procedures including:

- Safety and health risk or hazard analysis;
- Employee training requirements;
- Personal protective equipment (PPE);
- Daily safety meeting requirements;
- Medical surveillance;
- Site control measures (including dust control);
- Decontamination procedures; and
- Emergency response.

All work will be performed in accordance with current Health Safety, Security and Environmental (HSSE) guidelines, and ARC will identify all project-specific health and safety requirements, including:

- Scope with estimated dates and duration of activities;
- Assigned roles and responsibilities and specific training requirements;
- Development and maintenance of task safety and environmental analyses (TSEAs);
- Communications plan;
- Simultaneous operations (SIMOPS) plan;
- Traffic control plan (if necessary);
- Identification of control of work permitted activities; and
- Comprehensive list of project-related risks in a Work Risk Assessment (WRA).

8.1 Training

All Site workers and contractors will receive applicable training, as outlined in 29 Code of Federal Regulations (CFR 1910.120(e), and as stated in the HASP and Project HSSE Plan. Site-specific training will be covered at the pre-entry briefing, with an initial Site tour and review of Site conditions and hazards. Records of pre-entry briefings will be maintained at the project site. Planned training elements include:

- Identification of persons responsible for site-safety;
- Site-specific safety procedures;
- Site- and job-specific safety and health hazards;
- Project and task specific work risk assessment and mitigation;
- Use of PPE;
- Decontamination procedures; and
- Emergency response procedures.

Other required training, depending on the particular activity or level of involvement, includes Occupational Safety and Health Administration (OSHA) 40-hour training and annual 8-hour refresher courses. Other training may include, but is not limited to, competent personnel training for excavations and confined space. Copies of Site personnel OSHA certificates will be maintained at the Site and in employee personnel records.

8.2 Personal Protective Equipment

Minimum PPE requirements while performing the sampling task or other field activities described in this Vadose Zone Work Plan include:

- hard hat;
- safety glasses;
- steel-toe boots;
- long-sleeve shirts;
- high-visibility clothing or reflective vest; and
- nitrile and/or leather work gloves (as needed).

Additional PPE may be required depending on the work task and may include, but is not limited to, respirators, goggles, chemical protective suits, fall protection or hearing protection.

The use of respiratory protection is not anticipated to be necessary for the field activities identified in this Work Plan but each situation will be evaluated individually based on equipment used (potential to create dust), location (potential to encounter contaminated soils), and general field conditions. These items will be reviewed in a pre-start safety review that includes the Project Manager, field staff and the Site Safety Officer. If sufficient potential exists, all field personnel will be issued fit-tested respirators and monitoring will be conducted to determine actual dust or contaminant concentrations in the air. Actual use of respirators will only be required if concentrations exceed OSHA permissible exposure levels (PELs). Further detail on the use and selection of respirators is provided in the HASP.

8.3 Ground Disturbance Safety Requirements

All drilling or other activities involving ground disturbance must be evaluated for potential buried utilities that could interfere or create a safety hazard. Utility Service Alert (USA North) is the public underground utility location service for northern Nevada. The planned work area must be marked on the ground in white paint and a verbal description of the location or address must be provided to USA North at least 48 hours prior to the start of work. Additionally, a private locating service will be used to physically survey the planned work area in order to identify buried utilities that may not be registered with the public service, such as privately owned water lines, tanks or other buried materials. Air-knifing or hand-augering (hand clearance) will be conducted to a depth of at least 6.5 feet to confirm the absence of underground obstructions prior to drilling. However, in locations where soil samples must be collected from undisturbed soil within the top 6.5 feet, hand clearance shall be done in several adjacent locations no more than 2 feet from the drill location.

8.4 Work Risk Analysis

Work Risk Assessment (WRA) is a risk management tool for the identification and ranking of hazards associated with all aspects of a specific project or job before and after implementation of risk controls and preventive actions. Control of the hazards can be accomplished by elimination or substitution of the task, isolation of Site workers from the hazard, use of engineering or administrative controls, and/or the use of PPE. The WRA for the investigation activities described in this Vadose Zone Work Plan is provided in Appendix I and is subject to modification at any point before or during the implementation of work activities. A summary of potential hazards is provided in Table 8-1.

Comprehensive Task Safety and Environmental Analyses (TSEAs) will be completed for all field tasks required for the investigation activities before the work is initiated and will be developed jointly by the field staff conducting the work and the Project Safety Manager/Site Safety Officer. TSEAs will be kept at the Site at all times and will be reviewed by Site workers prior to, and throughout, the removal actions in order to identify new hazards or controls.

Table 8-1. Task Safety and Environmental Analysis Summary	
Field Activities	Potential Hazards
1. Borehole drilling and lithologic logging	<ul style="list-style-type: none">▪ Drilling into underground utilities.▪ Striking overhead lines or objects with drill mast.▪ Injury to hearing from noise.▪ Inhalation hazards from dust from drilling activities.▪ Physical injury from moving parts of machinery, hydraulic fluids, handling drill pipe.▪ Physical hazards to personnel on the ground in the vicinity of the heavy machinery▪ Physical hazards associated with use of hand tools.▪ Lifting and ergonomic hazard from handling soil cores.
2. Depth-discrete groundwater sampling	<ul style="list-style-type: none">▪ Skin irritation from dermal or eye contact with groundwater.▪ Slipping or falling on wet ground surface or drilling platform.▪ Burn or corrosion from sample preservatives.▪ Lifting and ergonomic hazards from lifting sample pump and sample cooler
3. Monitor well installation	<ul style="list-style-type: none">▪ Inhalation of silica sand, bentonite, or concrete dust.▪ Lifting and ergonomic hazard from handling heavy bags of sand, bentonite or concrete.
4. Monitor well development	<ul style="list-style-type: none">▪ Skin irritation from dermal or eye contact with purged groundwater.▪ Slipping or falling on uneven or wet ground surface.▪ Overhead hazard with pump truck mast and bailer.

Table 8-1. Task Safety and Environmental Analysis Summary	
Field Activities	Potential Hazards
5. Groundwater (monitor well) sampling)	<ul style="list-style-type: none"> ▪ Skin irritation from dermal or eye contact with groundwater. ▪ Slipping or falling on wet ground surface ▪ Burn or corrosion from sample preservatives. ▪ Lifting and ergonomic hazards from lifting sample pump and sample cooler
6. Vadose zone solids sample collection	<ul style="list-style-type: none"> ▪ Drilling hazards as listed above ▪ Back strain, ergonomic hazard, hand injury from handling soil cores.
7. Vadose zone moisture monitoring equipment installation and operation	<ul style="list-style-type: none"> ▪ Same as above for monitor well drilling and installation
8. Utility pipe line survey	<ul style="list-style-type: none"> ▪ Biological hazard from potential contact with spiders, insects or reptiles inside little used vaults or pipelines. ▪ Pinch points and lifting hazards opening manholes or vaults. ▪ Potential to encounter permit required confined spaces with possible atmospheric hazards. ▪ Tripping/walking hazards from building debris or unprotected basements (fall hazard).
9. General Activities	<ul style="list-style-type: none"> ▪ Heat stress due to high ambient temperature, lack of water, or lack of shade; or ▪ Hypothermia or frostbite due to low ambient temperature, improper clothing, damp or wet clothing, or lack of source for heat. ▪ Sunburn from lack of shade or improper clothing. ▪ Biological hazard from contact with spiders, insects or reptiles. ▪ Driving/mobilization related hazards. ▪ Wind related injuries including dust hazards to eyes.

Note: This is a partial list of potential hazards. The WRA(s) should be reviewed before commencement of work activities.

SECTION 9.0 REFERENCES

- American Society of Testing and Materials (ASTM), 1992, Standard D 2487-92. Classification of Soils for Engineering Purposes (Unified Soil Classification System).
- Anaconda Company, 1954, Plant Operations Report. Prepared by Mark Nesbitt. October 1954, Anaconda files at Yerington Mine Site.
- Brown and Caldwell, 2005a, *Data Summary Report for Process Areas Soils Characterization*, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. November 1.
- Brown and Caldwell, 2005b, *Data Summary Report for Process Areas Groundwater Conditions*, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. September 23.
- Brown and Caldwell, 2005c, *Radiological Data Compilation*, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. December 15.
- Brown and Caldwell, 2007a, *Draft Process Areas (OU-3) Remedial Investigation Work Plan*, Yerington Mine Site, Lyon County, Nevada. Prepared for the Atlantic Richfield Company. August 8.
- Brown and Caldwell, 2007b, *Data Management Plan for the Yerington Mine Site*, Yerington Mine Site, Lyon County, Nevada. Prepared for the Atlantic Richfield Company. July 26.
- Brown and Caldwell, 2008, *Second Step Hydrogeologic Framework Assessment Data Summary Report*, Yerington Mine Site, Lyon County, Nevada. Prepared for the Atlantic Richfield Company. October 15.
- Brown and Caldwell, 2009a, *Anaconda Evaporation Ponds Removal Action Characterization Data Summary Report, Revision 1*. Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. October 15.
- Brown and Caldwell, 2009b, *Air Quality Monitoring Program Data Summary Report*, Yerington Mine Site, Revision 2. Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. September 3.
- Brown and Caldwell, 2009c, *Background Soils Data Summary Report*, Yerington Mine Site, Revision 1. Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. March 9.

- Brown and Caldwell 2009d *Site-Wide Groundwater Monitoring Plan – Revision 1*, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. December 15.
- Brown and Caldwell, 2009e, *2008 Annual Groundwater Monitoring Report*, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. February 12.
- Brown and Caldwell 2009f, *Site-Wide Health and Safety Plan Yerington Mine Site - Revision 1*, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. December 21.
- Brown and Caldwell, 2010a, *Transite Pipe Removal Action Plan - Revision 1*, Yerington Mine Site, Lyon County Nevada. Prepared for the Atlantic Richfield Company. July 30.
- Brown and Caldwell, 2010b, *Draft Process Areas Radiological Materials Removal Action Plan*, Yerington Mine Site, Lyon County Nevada. Prepared for the Atlantic Richfield Company. July 6.
- Brown and Caldwell, 2010c, *2010 Groundwater Monitor Well Work Plan - Revision 2 Site-Wide Groundwater Operable Unit (OU-1) Remedial Investigation*, Yerington Mine Site. Prepared for Atlantic Richfield Company. July 22
- Brown and Caldwell, 2010d, *First Quarter 2010 Groundwater Monitoring Report*, Yerington Mine Site. Prepared for Atlantic Richfield Company. June 2010
- Brown and Caldwell, 2010e, *2009 Annual Groundwater Monitoring Report*, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. March 8.
- Brown and Caldwell and Integral Consulting Inc., 2007, *Remedial Investigation Work Plan Site-wide Groundwater (OU-1)*, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. November 16.
- Brown and Caldwell and Integral Consulting, 2009, *Conceptual Site Model - Revision 3*, Yerington Mine Site, Lyon County, Nevada, Prepared for Atlantic Richfield Company. January 30.
- Bureau of Land Management, Carson City Field Office, 2004, BLM Yerington Mine Health and Safety Plan.
- Campbell, J.D., 1973, *Pore Pressures and Volume Changes in Unsaturated Soils*, PhD. Dissertation, University of Illinois at Urbana-Champaign, 104 pp.
- Cember, Herman, 1996, *Introduction to Health Physics 3rd Ed.* McGraw-Hill, New York.
- Charbeneau, R.J., *Groundwater Hydraulics and Pollutant Transport*, Prentice Hall, 2000.

- CH2M Hill, 2010. Technical Memorandum: Drywells, Sumps, and Source Areas Located within the Historic Anaconda Yerington Mine Site Process Areas Operable Unit (OU-3). Prepared on behalf of EPA Region 9. May 7.
- Environmental Standards, Inc. (ESI) and Brown and Caldwell, 2009, Quality Assurance Project Plan, Revision 5, Yerington Mine Site. Prepared for Atlantic Richfield. May 20.
- EPA, 1996, Ground Water Issue, Low-Flow (Minimal Drawdown) Ground-Water Sampling Procedures, by R. W. Puls and M.J. Barcelona. Office of Research and Development. EPA/540/S-95/504.
- EPA, 2002, Guidance for Comparing Background and Chemical Concentrations in Soil for CERCLA Sites, EPA 540-R-01-003, OSWER 9285.7-41, September.
- EPA, 2004, USEPA Contract Laboratory Program, National Functional Guidelines for Inorganic Data Review, EPA 540-R-04-004, OSWER 9240.1-45, October.
- EPA, 2006, Guidance on Systematic Planning Using the Data Quality Objectives Process. QA/G-4. Office of Environmental Information, Washington DC. EPA/240/B-06/001.
- EPA, 2007, Statement of Work, Administrative Order for Remedial Investigation and Feasibility Study, Anaconda Copper Mine, Yerington NV. EPA Docket No. 9-2007-0005. January 12.
- Evett, S.R., 2003, Soil Water Measurement by Time Domain Reflectometry, Encyclopedia of Water Science, Marcel Dekker.
- Fredlund, D.G., Xing, A., and Huang, S., 1994, Predicting the permeability function for unsaturated soil using the soil-water characteristic curve, Canadian Geotechnical Journal, Vol. 31, No. 3, pp. 533-546.
- Huxel, C.J., Jr., 1969, Water Resources and Development in Mason Valley, Lyon and Mineral Counties, Nevada, 1948-1965, Nevada Division of Water Resources Water Resources Bulletin No. 38. Prepared in cooperation with the U.S. Geological Survey.
- Looney, B.B., and Falta, R.W., 2000, Vadose Zone – Science and Technology Solutions, Edited by Brian B. Looney and Ronald W. Falta, Battelle Press, Volume 1, p. 143.
- Mining Engineering, 1967, Copper Precipitation Methods at Week Heights, by Howard W. Jacky, June 1967.
- Proffett, J. M., Jr., and Dilles, J. H., 1984, Geologic Map of the Yerington District, Nevada. Nevada Bureau of Mines and Geology, Map 77.

- Rimon, Y., Dahan, O., Nativ, R., and Geyer, S., 2007, Water percolation through the deep vadose zone and groundwater recharge: Preliminary results based on a new vadose zone monitoring system, *Water Resources Research*, Vol. 43, W05402, doi:10.1029/2006WR004855.
- Seitz, H. R., Van Denburgh, A. S. and La Carma, R. J., 1982, Ground-Water Quality Downgradient from Copper-One Milling Wastes at Weed Heights, Lyon County, Nevada, U. S. Geological Survey Open-File Report 80-1217.
- Shacklette, H. T. and Boerngen, J. G., 1984, Element Concentrations in Soils and Other Surficial Materials of the Conterminous United States, U. S. Geological Survey Professional Paper 1270.
- Skillings Mining Review, 1972, Yerington Copper Mine, by David N. Skillings Jr., May 20, 1972, Vol. 61, No. 21.
- Team 9, Superfund Technical Assessment and Response Team (START), 2008. Anaconda Mine Radiation Assessment Letter Report. Prepared for EPA Emergency Response Section under Technical Directive Document No. TO1-09-07-02-0001. August 15.
- UNFAO, 1998, Allen, R.G., Pereira, L.S., Raes, D., and Smith, M., “Crop evapo-transpiration; Guidelines for computing crop water requirements,” FAO Irrigation and Drainage Paper No. 56, Rome, Italy.
- U.S. Bureau of Mines, 1958, Methods and Operations at the Yerington Copper Mine and Plant of the anaconda Company, Weed Heights, Nev., by M. Claire Smith; Information Circular 7848, Department of the Interior (DOI).
- Western Regional Climate Center (WRCC), 2007, web site (<http://www.wrcc.dri.edu/>)
- van Genuchten, M. Th., 1980, *A Closed-Form Equation for Predicting the Hydraulic Conductivity Of Unsaturated Soils*, Soil Science Society of America Journal, vol. 44, p. 892-898.